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EVALUATION AND DEVELOPMENT OF ULTRASOUND IMAGING METHODS IN VETERINARY CLINIC

Master of Science Thesis

Examiners: prof. Hannu Eskola
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ABSTRACT

EMMI VEHANEN: Evaluation and development of ultrasound imaging methods in veterinary clinic
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The aim of this Master's Thesis was to evaluate and develope ultrasound imaging methods in veterinary clinics. Ultrasound is a beneficial imaging method in many ways and it is widely used in the field of veterinary medicine.

In the literature part of this thesis, ultrasound imaging principles; properties of ultrasound, ultrasound device and transducer, beam properties and resolution, imaging modes and quality assurance are studied. In addition, chapter 3 reviews the animal ultrasound specifically; preparation before ultrasound examinations, examination procedure, device and transducer, applications and image quality.

The actual research phase of this thesis is formed from an inter-net-based questionnaire that was sent to veterinary clinics across Finland. The questionnaire consisted of 11 questions. The questions were composed so that they would give as much information as possible from the ultrasound imaging methods in veterinary clinics. Some of the questions were open-ended, so veterinarians had a possibility to freely tell their opinion.

Based on the answers, almost every veterinary clinic is using ultrasound. It is used for several different applications and 75% of the respondents used ultrasound for at least for one of fifteen patients. However, the questionnaire's answers revealed several deficiencies and challenges that could be improved. The most important developmental objects are associate with insufficient education, quality assurance, societal pressure and preparation instructions.

TIIVISTELMÄ

EMMI VEHANEN: Ultraäänikuvantaminen eläinklinikalla – arviointi ja kehittäminen
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Tämän tutkimuksen päätarkoitus on arvioida ja kehittää ultraäänikuvantamista eläinklinikoilla. Ultraääni on monella tapaa hyödyllinen kuvantamisväline ja sitä käytetään laajalti eläinlääketieteessä.

Työn kirjallisessa osiossa perehdytään ultraäänikuvantamisen prinsiippeihin. Syvemmän tarkastelun kohteena on; ultraäänen ominaisuudet, ultraäänilaite ja anturi, ultraäänisäteen ominaisuudet ja resoluutio, kuvausmoodit sekä laaduntarkkailu. Toinen kirjallinen osio, kappale 3, tarkastelee lähemmin ultraäänen käyttöä eläinkilinkoilla. Pääpaino on ultraäänitutkimukseen valmistautumisessa, tutkimuksen aikaisissa toimintatavoissa, ultraäänilaitteella ja anturilla, ultraäänen erilaisissa sovelluskohteissa sekä kuvanlaadussa.

Työn varsinainen tutkimusosuus koostui kyselytutkimuksesta, mikä lähetettiin eläinkilinoille eri puolelle Suomea. Kysely koostui 11 kysymyksestä, joiden tarkoituksena oli selvittää mahdollisimman kattavasti ultraäänen käyttöä eläinklinikoilla. Osa kysymyksistä oli avoimia, jolloin eläinlääkäreillä oli mahdollisuus kertoa vapaasti omista näkemyksistään.

Tulosten perusteella ultraäänilaite on käytössä lähes kaikilla eläinklinikoilla. Sitä käytetään useisiin erilaisiin tutkimuksiin ja 75% vastaajista käyttää ultraääntä vähintään yhdelle viidestätoista potilaasta. Vastaukset paljastivat kuitenkin epäkohtia ja haasteita. Erityisinä kehityskohtina esiin nousi puutteellinen ja vähäinen koulutus, laaduntarkkailu, yhteiskunnan tuomat paineet ja vaatimukset sekä valmistautumisohjeiden antaminen ja niiden noudattaminen.

PREFACE

This thesis was done between December 2017 and June 2018. Firstly, I would like to thank my dear friend, who was an inspiration to the subject of this thesis. I want to give my gratitude also to professor Hannu Eskola for advice and help with the work. Special thanks belong to all of you veterinarians, who had time and desire to respond to the questionnaire.

Last but not least, I would like to thank my friends and family for their encouragement and support in difficult and desperate moments and especially my boyfriend, who has been supportive during the Master's Degree.

Now it's done.

Kirkkonummi, 30.7.2018

Emmi Vehanen

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LIST OF SYMBOLS AND ABBREVIATIONS

α	Attenuation coefficient; describes the attenuation of ultrasound in tissue
A-mode	Ultrasound imaging mode (Amplitude); echo amplitude is shown on the y-axis as a function of the time on the x-axis
B-mode	Ultrasound imaging mode (Brightness); the amplitude of echoes, are represented by a brightness value in two dimensions
c	Speed of ultrasound in medium (ms^{-1})
CPU	Central processing data
d	Diameter of transducer (mm^2)
E	Energy of ultrasound
f	Frequency of ultrasound (Hz)
FNA	Fine-needle aspiration
FNF	Fine-needle fenestration
FOV	Field of view
FR	Frame rate; inverse frame time
FS %	Fractional shortening; contractility of the ventricle expressed as a percentage
FT	Frame time: time that is demanded to achieve a complete image
FPGA	Field-programmable gate array
I	Intensity of ultrasound (Wm^{-2})
I_0	Intensity of reference ultrasound
K	Ratio of bulk elastic modulus
λ	Wavelength (m)
LVIDd	Left ventricular internal dimension in diastole
LVIDs	Left ventricular internal dimension in systole
M-mode	Ultrasound imaging mode (Motion); echo information is shown real-time
P	Power (W)
Pm	Maximal pressure in the medium
p	Density of the medium (kgm^{-3})
PRF	Pulse repetition frequency; time between two subsequent pulses

PRP	Pulse repetition period; inverse pulse repetition frequency
PZT	Zirconate titanate
r	Radius of transducer (mm)
R_I	Intensity of reflection coefficient; describes how much of the sound intensity is reflected
SPL	Spatial pulse length
t	Time (s)
TGC	Time gain compensation, ultrasound setting parameter
θ_C	Critical angle; angle where ultrasound beam is refracted so, that no ultrasound is transmitted across boundary surface
θi	Refraction angle
θ_t	Incident angle
T_I	Intensity transmission coefficient; describes the fraction of the intensity that is transmitted in-to medium
v	Velocity
Z	Acoustic impedance ($kgm^{-2}s^{-1}$)

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1. INTRODUCTION

The use of ultrasound imaging in veterinary medicine started almost at the same time as its use in the human medical field, which began in the early 1960s [1]. The first registered diagnostic ultrasound imaging in veterinary medicine, was a gestation identification of a sheep in 1966. Over the years, technology and ultrasound devices have developed and the awareness of benefits and ultrasound imaging techniques has improved substantially. As a result, ultrasound is now a widely used imaging method in the field of veterinary medicine. [2]

Ultrasound is a beneficial imaging method primarily because it is fast, safe and portable, in addition to its high-quality soft tissue contrast [3]. Studies have shown that it has no harmful biological effects to animals and because it is non-invasive, ultrasound examinations can normally be performed without sedation or anaesthesia. [2] However, ultrasound imaging in veterinary medicine is also quite challenging. To prepare accurate and high-quality diagnostic examinations, veterinarians must know anatomy and physiology of different animal species and all breed-specific pathologies. [1] In addition, this technique requires time, practice and experience to be able to separate the normal anatomy from artefacts and abnormalities [2].

The most common application of ultrasound examination in veterinary medicine is gestation identification. Other applications are for instance, examinations of urinary bladder disorders, tumours, heart and blood flow and taking fine-needle samples with ultrasound guidance. Continuous development of technology and new clinical research studies, will engender even more ultrasound imaging applications in the future [1].

The idea of this thesis originated from a discussion with a veterinarian. Another inspiration was lack and difficulty with finding specific literature and material on ultrasound examinations of animals. Based on this, the first aim of this thesis was to become acquainted with the use of ultrasound imaging in veterinary clinics. The second goal was evaluation and development of the ultrasound imaging methods in veterinary clinics based on literature and a questionnaire.

Chapters 2 and 3 of this thesis review the theoretical background. Chapter 2 explains ultrasound imaging principles in general; properties of ultra-sound, ultrasound device and transducer, beam properties and resolution, imaging modes and quality assurance are studied. Chapter 3 reviews the animal ultra-sound specifically; preparation before ultrasound examinations, examination procedure, device and transducer, applications and image quality.

The material and methods use in this research are discussed in chapter 4. The information on the actual research phase of this thesis was collected from an internet-based questionnaire that was sent to veterinary clinics across Finland. The results of this questionnaire are reviewed in chapter 5.

In the discussion, chapter 6, the development suggestions are revealed. Development suggestions were mostly created based on, what veterinarians thought were most challenging matters in ultrasound examinations.

2. ULTRASOUND IMAGING

Ultrasound is mechanical wave motion that propagates in a medium. The oscillation frequency is beyond the human hearing range, over 20 kHz. In medical ultrasounds, the ultrasound wave is produced by oscillating piezoelectric crystals. When the crystal is in contact with the skin's surface, the changes in the thickness of the crystal develops a mechanical energy pulse, which penetrates into the tissue. [3]

The propagation of the ultrasound wave leads to different interactions at tissue boundaries. These interactions are reflection, scattering, refraction, absorption and attenuation. The ultrasound image is formed from information returning echoes from the tissues. Echo information is based on two factors: the intensity of the returning echo and time elapsed between sending the echo and its return. Time is turned to distance, which indicates the echo's maximum depth [4]

2.1 Properties of ultrasound

Wavelength (λ) is the distance between two contiguous points, that are in the same phase. Frequency (f) is the number of wave oscillations during one wave cycle. In medical use, the frequency of ultrasound ranges from 2 to 10 MHz. Time duration of one wave cycle is called a period, which can be calculated with equation 1:

$$Period = \frac{1}{f} \tag{1}$$

where frequency is expressed in cycles per second. The speed of sound is the distance that a sound wave travels in a period of a time. [4] Because frequency and period are inversely related, the speed of a sound in a medium can be mathematically stated as follows:

$$c = \lambda f \tag{2}$$

where λ is the wavelength and f is the frequency [4]. The speed of a sound wave can be also calculated with another equation (3):

$$c = \sqrt{\frac{K}{p_0}} \tag{3}$$

where p_0 is the density of the medium and K is the ratio of bulk elastic modulus. In ultrasound devices the average speed of sound is often assumed to be 1540 m/s. [5] The more compressible the matter, the lower the speed of a sound; conversely, the less compressible the matter, the faster is the speed of a sound. For instance, the average speed of sound in air is 330 m/s, in fat 1450 m/s and in muscle 1600 m/s. [4] Speeds of sound are presented in table 1.

The propagation of an ultrasound wave shifts energy through the medium. In medical ultrasounds, this energy is defined as the beam's intensity. The intensity of an ultrasound wave (I) can be determined as power (P) per unit area (a) or as energy (E) per unit area (a) multiplied with time (t):

$$I = \frac{P}{a} = \frac{E}{t \cdot a} \tag{4}$$

The unit of intensity is watt/cm^2. Intensity is often expressed as decibel (dB) because the logarithmic scale is most appropriate for the huge scale of magnitudes. The unit transformation is achieved by using equation (5):

$$dB = 10 \log \frac{I}{I_0} \tag{5}$$

where I is intensity and I_0 is the reference intensity. When an ultrasound wave has a greater intensity than the reference wave, a positive decibel value results. Correspondingly, a negative decibel value results when an ultrasound wave has a lower intensity than reference intensity. The intensity of an ultrasound wave is related to the maximal pressure (p_m) in the medium, represented by the following equation:

$$I = \frac{P_m^2}{2pc} \tag{6}$$

where (p) is the density of the medium in grams per cubic centimetre and (c) is the velocity of sound in the medium. [6]

Acoustic impedance (Z) of a material can be calculated by multiplying density (p) with speed of sound (c):

$$z = pc \tag{7}$$

The SI unit of acoustic impedance has a specific name the *rayl*. One rayl is equal to 1kg/(m^{2}s). The produce of an ultrasound image in the pulse-echo technique is based on differences in acoustic impedances, which causes reflection and transmission of ultrasound energy [4]. Some typical acoustic impedances are represented in table 1.

When an ultrasound wave reaches a boundary between two mediums, a part of the wave energy reflects back to the initial medium. The rest of the energy penetrates the surface and refracts to the other medium. [4] The intensity reflection coefficient can be calculated with equation (8);

$$R_I = \frac{I_r}{I_i} = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2 \tag{8}$$

Intensity reflection coefficient describes how much of the sound intensity is reflected. Another value that is closely related to intensity reflection is intensity transmission coefficient (T_I), which can be calculated with equation (9);

$$T_I = 1 - R_I \tag{9}$$

The intensity transmission coefficient tells the fraction of the intensity that is transmitted into medium. For instance, the reflection coefficient for a fat-muscle boundary surface is 0.015 and therefore transmission coefficient is 0.985. This means that 1.5 % of the ultrasound intensity is reflected and 98.5 % is moved forward deeper in the tissue. [4]

During propagation the ultrasound energy attenuates exponentially. Attenuation is a result from scattering and absorption:

$$\mu = \mu_a + \mu_s \tag{10}$$

where μ_a is the intensity absorption coefficient and μ_s is the intensity scattering coefficient [5]. Attenuation is high in bone and gases. For instance, a boundary between soft tissue and bone is a strong reflector. This means that the majority of the sound energy is reflected backwards and only a fraction is able, to penetrate through the interface [7]. The attenuation coefficient (α) is a quantity used to describe the attenuation of ultrasound in tissues. The attenuation coefficient can be determined by using equation (11):

$$\alpha = AdBcm^{-1}MHz^{-1} \tag{11}$$

where A for most soft tissues is approximately 1 (A≈1). As seen from equation 11, the attenuation coefficient increases with the frequency of the ultrasound beam. [5] The unit for the attenuation coefficient is decibels per centimetre (dB/cm) [4]. The attenuation coefficient of different tissue for the 1-MHz ultrasound is represented in table 1.

Refraction occurs at a tissue boundary, when the beam is not perpendicular to the boundary. Refraction describes the change in the direction of the ultrasound wave. The relationship between the speed of sound in a medium (c), the incident angle (θ_t) and the refraction angle (θ_i) is described by Snell's law:

$$\frac{\sin\theta_t}{\sin\theta_i} = \frac{c_2}{c_1} \tag{12}$$

The ultrasound beam may be refracted so, that no ultrasound is transmitted across the interface. This incident angle at which this phenomenon occurs is called the critical angle (θc). The critical angle can be calculated with equation (13):

$$\frac{\sin\theta_t}{\sin 90°} = \frac{C_2}{C_1} \tag{13}$$

Refraction easily causes artefacts in ultrasound images. For example, because of a refraction the apparent object a viewer sees is often located in a different place than the true object. [6]

Scattering is an interaction that occurs more randomly than refraction and reflection. The size of the obstacle compared to the wavelength has an impact on the scattering behaviour. Ultrasound energy will scatter in different directions in situations where the size of the barrier is comparable or smaller than the wavelength of the ultrasound. A scattering process called Rayleigh scattering, takes place in when the scattering targets are remarkably smaller than the ultrasound wavelength. One example of Rayleigh scatterers are red blood cells. [6]

Table 1. *Ultrasonic properties of biological tissue: acoustic impedance (Z), attenuation coefficient (α) and velocity of sound (c).*

Properties of different tissues						
Tissue	**z (Rayls)**	Ref.	**α at 1 MHz (dB/cm)**	Ref.	**c (m/s)**	Ref.
Air	$0{,}0004 \times 10^6$	[4]	11.99	[8]	330	[4]
Blood	$1{,}65 \times 10^6$	[4]	0.18	[4]	1560	[4]
Fat	$1{,}34 \times 10^6$	[4]	0.6	[6]	1450	[4]
Kidney	$1{,}63 \times 10^6$	[4]	1.0	[6]	1565	[4]
Liver	$1{,}65 \times 10^6$	[4]	0.9	[6]	1555	[4]
Lung	$0{,}18 \times 10^6$	[4]	40	[4]	600	[4]
Muscle	$1{,}71 \times 10^6$	[4]	0.2 - 0.6	[4]	1600	[4]
Soft tissue	$1{,}63 \times 10^6$	[4]	0.3-0.8	[4]	1050	[4]
Skull bone	$7{,}8 \times 10^6$	[6]	20	[6]	4080	[4]
Water	$1{,}48 \times 10^6$	[4]	0.002	[4]	1480	[4]

2.2 Ultrasound device and transducer

The main components of an ultrasound device are the monitor, transducer and a large amount of signal processing electronics [8]. The transducer produces and receives the ultrasound pulse. Inside the transducer is a crystal made of piezoelectric material [3]. In medical imaging applications, the ultrasound transducer crystal is often man-made ceramic ferroelectrics, such as lead zirconate titanate (PZT) [6]. Piezoelectric crystals start to oscillate when they are combined with an external electric field. When the crystal is in contact with the skin surface, the volume of the crystal changes, which produces the mechanical ultrasound wave [3]. After producing and transmitting the ultrasound wave, the transducer turns to receiver and detects the echoes from the tissues by converting them to electric signals [8]. This method is called pulse-echo technique.

In the pulse-echo mode, the features of the pulse are dependent on the damping characteristics of the transducer element. In soft tissues, the time delay between the send pulse and the detection of the echo returning from the body is directly related to the depth of the boundary surface:

$$Time(\mu s) = \frac{2D(cm)}{c(cm/\mu s)} = \frac{2D(cm)}{0{,}154 cm/\mu s} \tag{14}$$

where c, is the speed of a sound, D is the distance from the transducer to the reflector and the number 2 represents the round-trip distance. If the time and speed of a sound in soft tissue (0.154 cm/µs) is known, the distance can be calculated with the following equation:

$$Distance\ (cm) = \frac{c(cm/\mu s) \times Time(\mu s)}{2} \tag{15}$$

Pulse repetition frequency (PRF) describes the number of times, the transducer is pulsed per second. This frequency has units of pulses per second, or Hertz, and where the image is formed depends on the tissue depths. This dependency is because, in pulse-echo technique, the previous pulse echo has to be received before a new pulse can be sent [3;6]. In a normal clinical ultrasound, the PRF value in M-mode is 500 Hz; in Real-time mode, it is 2000-4000Hz; and in pulse Doppler, it is 4000-12000 Hz [4]. The inverse PRF is known as pulse repetition period (PRP):

$$PRP = \frac{1}{PRF} \tag{16}$$

PRP describes the time between two subsequent pulses. A typical PRP value for clinical ultrasound in M-mode is 2000 µs, in real-time mode 500-250 µs and in pulse Doppler 250-83 µs [4].

PRP affects the frame time (FT), or the time necessary to achieve a complete image. This value can be calculated with equation (17) by multiplying PRP with number of scan lines (N):

$$FT = PRP*N \quad (17)$$

FT can be shortened by achieving two or more scan lines at the same time. The inverse of the frame time is frame rate (FR):

$$FR = \frac{1}{FT} \quad (18)$$

Frame rate has an inverse relationship with PRP, maximum field of view (FOV) and the number of scan lines. Because of this relationship, an increase in any of the three variables decreases the FR [6].

Figure 1 illustrates a single-element ultrasound transducer.

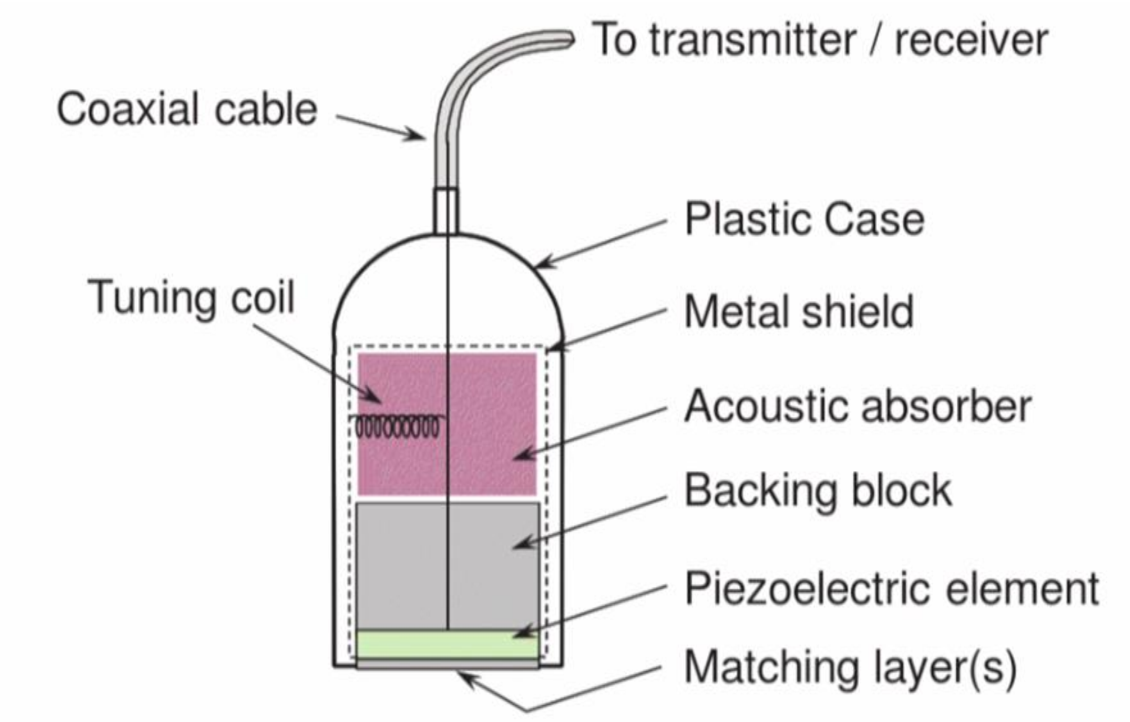

Figure 1. *Single-element ultrasound transducer [4].*

An ultrasound transducer consists of a cable that connects the transmitter/receiver, plastic case, metal shield, acoustic absorber, tuning coil, backing block, piezoelectric element and matching layers. The aim of the matching layer is to minimize the acoustic impedance differences between the transducer and the patient. The backing block, which lays on the back of the piezoelectric element, attenuates ultrasound signals from the housing and absorbs the reciprocal directed ultrasound signal. Another function of backing block is to dampen the transducer oscillation to create an ultrasound pulse with a shot spatial pulse length [4]. The layers after the backing block is made up of electric and acoustic insulators. Acoustic absorber prevents external oscillations from causing a voltage in the active piezoelectric elements. All the layers are covered with a plastic case, which allows the user to hold the transducer safely [9].

The ultrasound transducer has developed considerably over the years, beginning as simple fixed crystals and developing into mechanically scanned elements. Now, different types of multielement arrays – linear, phased, curvilinear and annual are used. The advantage of multielement array transducers is that each piezoelectric element can be independently fired. This method allows a larger flexibility in applications, when an ultrasound beam can be focused and shaped to achieve a better outcome [9]. Typically, a multielement array consists of 128 to 512 rectangular elements. One element is normally several millimetres long and less than half a wavelength wide [4]. Figure 2, below, introduces a linear- and phase array and the difference between functions.

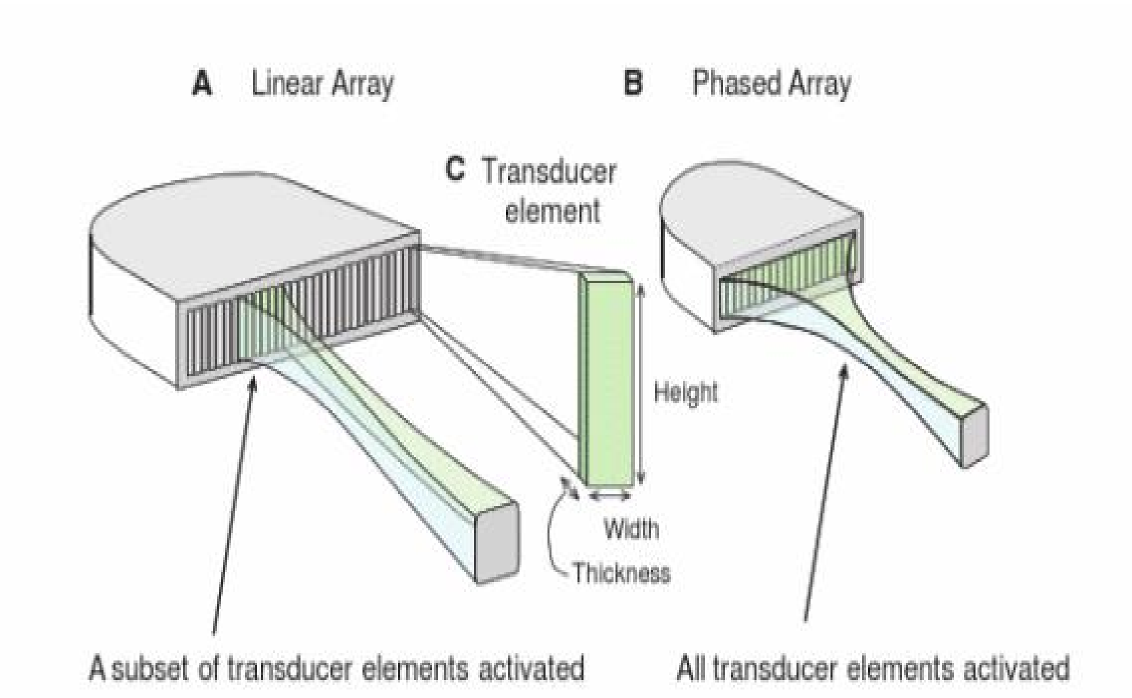

Figure 2. *Linear array and phased array [4].*

As figure 2 depicts, the function of a linear array is based on firing a small group of elements, which produces the ultrasound beam. In a phased array, all the elements are activated [4]. The ultrasound beam attempts to disperse during the penetration, which decreases the image quality. Thus, it is often necessary to focus and steer the beam with a specific transducer delay [3].

Before the ultrasonic image is displayed in the monitor, the echo returning from the body goes through a signal processing. First, the returning echoes from the body are converted into electric signals through the transducer [8]. The signals of returning echoes are weak and therefore are amplified in a pre-amplifier [3]. Afterward the signals undergo A/D conversion, which converts the analogue signals to digital. From A/D conversion, the signals move to the FPGA (field-programmable gate array) where they goes through different digital signal processes, (filtering, logarithm compression, detection) and then forms digital beam data stream. [8]. Filtering is performed, for instance, to reduce noise and interferences [3]. Finally, the beam data stream is sent to CPU (central processing unit), where it goes through scan transformation and video processing. After these stages, the ultrasonic images can be seen on the monitor [8].

Figure 3, below,presents a block diagram of the SonoScape portable ultrasonic diagnostic system.

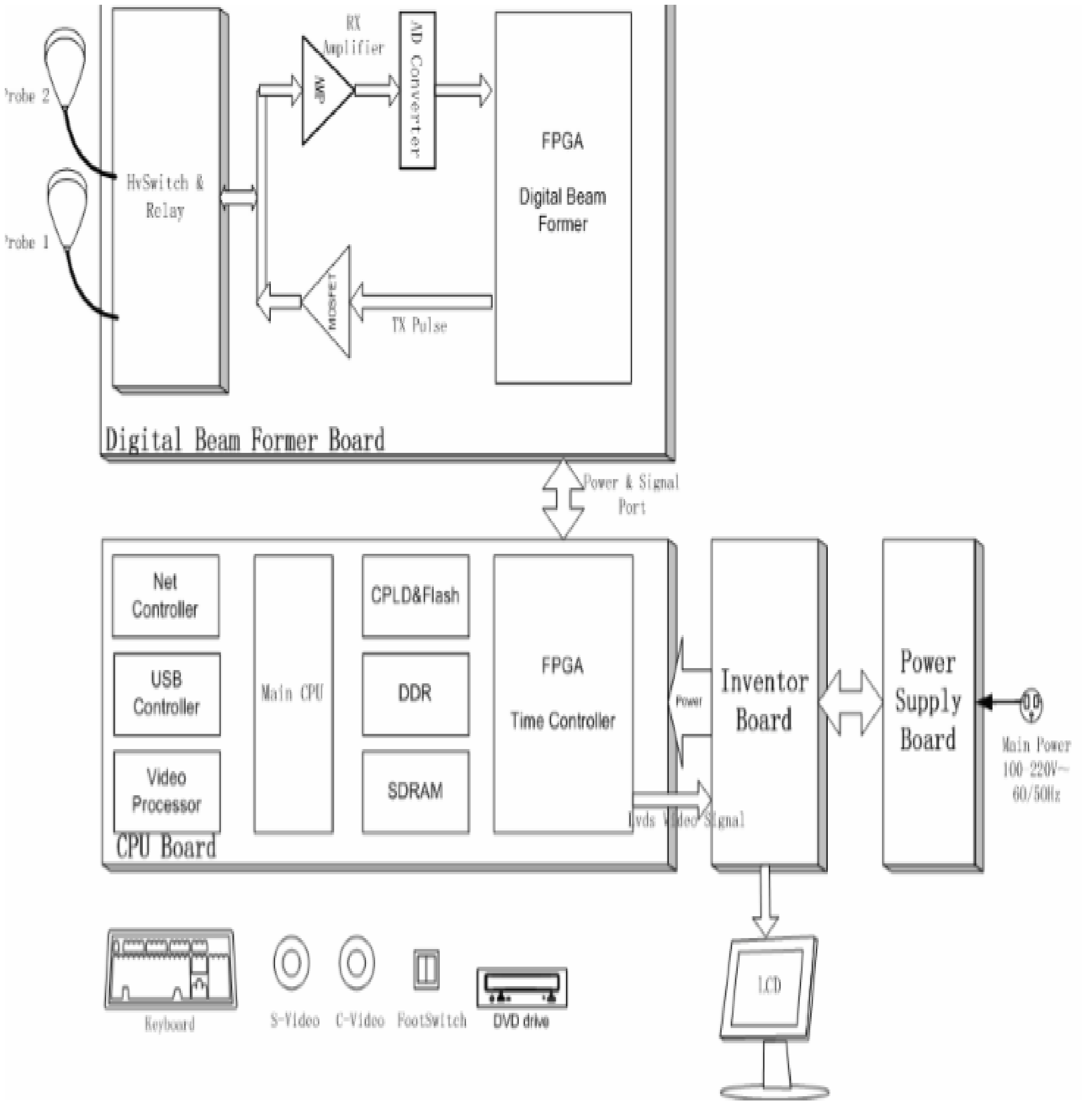

Figure 3. *Block diagram of portable ultrasonic diagnostic system [8].*

2.3 Beam properties and resolution

An ultrasound beam is divided into two fields: near and far. The length of the near field, also called Fresnel zone, is dependent on the propagation of the wavelength and the diameter of transducer;

$$\text{Near field length} = \frac{d^2}{4\lambda} = \frac{r^2}{\lambda} \tag{19}$$

where d is the diameter of the transducer, r is the transducer radius and λ is the wavelength of ultrasound in the propagation medium. In soft tissues, the length of near field can be calculated as a function of frequency and diameter:

$$\text{Near field length (soft tissue)} = \frac{d^2(mm^2)f(MHz)}{4\cdot 1{,}54mm} \tag{20}$$

The equation of near field length in soft tissues reflects that the distance of the near field increases as the operation frequency and physical diameter of the transducer are increased [4].

The far field is where the beam diverges. The angle of the ultrasound beam divergence θ for the far field is given by the following equation:

$$sin\,\theta = 1.22\frac{\lambda}{d} \tag{21}$$

where λ is the wavelength of the ultrasound propagation medium and d is the effective diameter of the transducer. The intensity of ultrasound in the far field decreases monotonically when distance decreases [4].

Resolution describes the ability to separate objects and details from each other. Spatial resolution can be determined in three different dimensions: axial, lateral and slice thickness (figure 4) [4].

Axial resolution, expressed in blue in figure 4, is ability to separate two closely located objects in the direction of the beam and is independent of depth. Obtaining a satisfactory axial resolution, demands that the returning echoes are separated without overlapping. To avoid overlap of returning echoes, the minimal separation distance between two reflectors should be at least one-half of the SPL (spatial pulse length).

Lateral resolution, indicated in red in figure 4, is the ability to separate two closely located objects in orthogonal to the beam directions. Lateral resolution is determined by the beam diameter, and the resolution is best at the near field-far field boundary, where the efficient beam diameter is about equal to one-half of the transducer diameter. Lateral resolution is unsatisfactory in regions near and far from the transducer surface.

Elevational resolution, or slice-thickness, is shown violet in figure 4. Elevational dimension notably affects resolution, especially with respect to volume averaging of acoustic details in the areas close to the transducer and in the far field beyond the focal zone. [4] The three dimensions of spatial resolution are illustrated in figure 4.

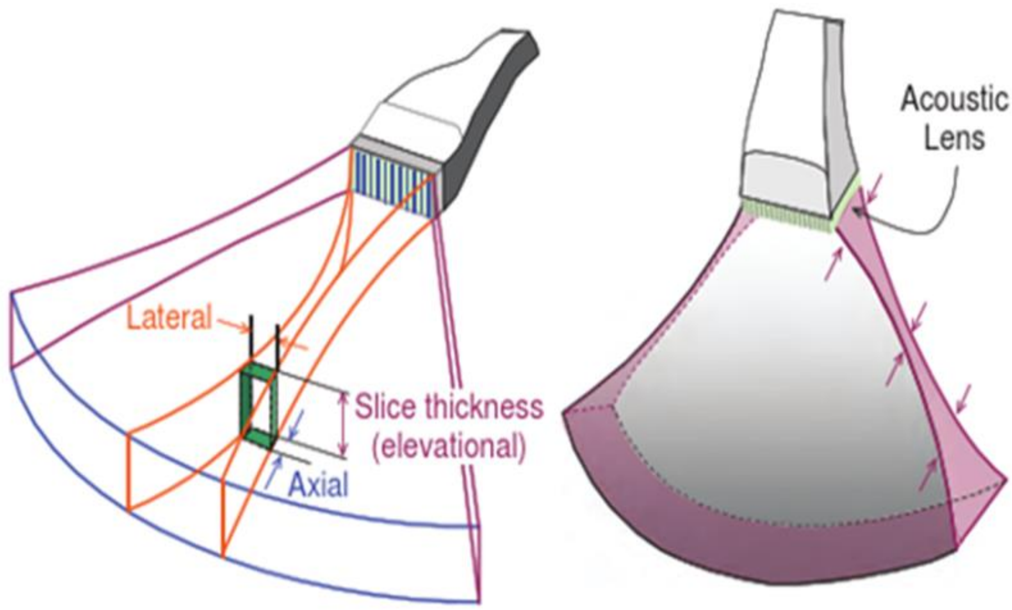

Figure 4. *Lateral, spatial and axial resolution [4].*

2.4 Imaging modes and

Ultrasound devices can display image information in different forms. The monitoring method varies according to the image applications [3]. One of the modes previously commonly used is A-mode (amplitude), where echoes returning from the tissues are presented as signals on an oscilloscope. In a coordinate system, the echo amplitude is shown on the y-axis as a function of the time on the x-axis. If the velocity of a sound is assumed to be constant, then the x-axis can be presented as the distance from the ultrasound transducer [6].

In B-mode (brightness), the amplitude of echoes, are represented by a brightness value in two dimensions (x- and y-coordinates). This means that more echogenic areas in the patient are seen brighter in the image. In B-mode tissues can be examined either statically or in real-time [6].

M-mode (motion) is used specifically to study moving structures. The echo information from an ultrasound beam passing through a moving structure is expressed as a function of time, where time is on the x-axis and depth is on the y-axis [6]. M-mode is particularly useful in heart examinations, where for instance the contraction of left ventricle and the movement of the valves can be visualized effectively [3].

One imaging technique is Doppler, which is mainly used to examine blood vessels and flow. This method is based on the Doppler phenomenon, meaning that the frequency of transmitted and received ultrasound is different depending on the motion of the medium. The shift of frequency can be mathematically determined with equation 22:

$$\Delta f = 2f \cdot \left(\frac{v}{c}\right) \cos\theta \tag{22}$$

where f is the frequency of the source, c is speed of ultrasound in the medium, v is velocity and θ is the angle between the transducer and the direction of the object's motion [6]. Doppler examination of blood flow is based on frequency shift caused by the motion velocity of blood cells. When blood flow is constant (laminar), a frequency shift corresponding to a certain flow profile appears, and when the flow becomes turbulent, the registered Doppler signal contains several frequencies. The angle between transducer and flow direction, has a significant impact on registered Doppler signals. To avoid inaccuracy, angles over 60 degrees should not be used [3].

There are several different Doppler techniques. The first technique is continuous wave Doppler, which is the simplest way to measure blood velocity. This technique requires two transducers: other one transmits the incident ultrasound and the other detects the continuous echoes [4]. Continuous wave Doppler, enables the detection of rapid flows, but the location information is overlooked [3]. A second Doppler method is pulse wave Doppler, which combines the sound of a speed determination of continuous wave Doppler and the range dissociation of pulse-echo imaging. A third technique is Colour flow Doppler. Colour flow Doppler enables the display of blood flow with different colours. Direction of the flow and the speed of a sound are defined for several positions within a subarea of the image and, afterward, colour encoded. The blood moving towards the transducer is represented in red and the blood moving away from the transducer is represented by shades of blue. [4] Another Doppler method is energy or power Doppler, where the signal is colour coded. This method can be used especially, to examine tiny and deep flows, but it is not suited for measurements of flow velocity [3]. Finally, energy Doppler relies on the amplitude of the Doppler signal and disregards the phase information [4].

2.5 Artefacts

The formation of ultrasound imaging develops inevitable phenomena, that produces image faults, called artefacts. Most of the artefacts are unwanted, whereupon they disturb the interpretation of the ultrasound image. In some situation artefacts can be beneficial and help to diagnose characteristics of tissue structures [3]. Some imaging artefacts originate from improper scanning techniques and others arise from physical limitations of the technique. It is impossible to prevent all artefacts, but by understanding the physical features of an ultrasound system, propagation of the sound in different tissues and image processing assumptions, one can determine the reasons for artefacts [10].

When two tissues have different velocities of sound, refraction may occur, and thus the direction of the ultrasound wave changes. Displacement of anatomical structure depends on the position of the transducer and the angle of incidence with the tissue interfaces. As a result of refraction, a “ghosting” artefact appears, which means that structures are either duplicated or appear wider than the truly are in the ultrasound image (figure 5). [10]

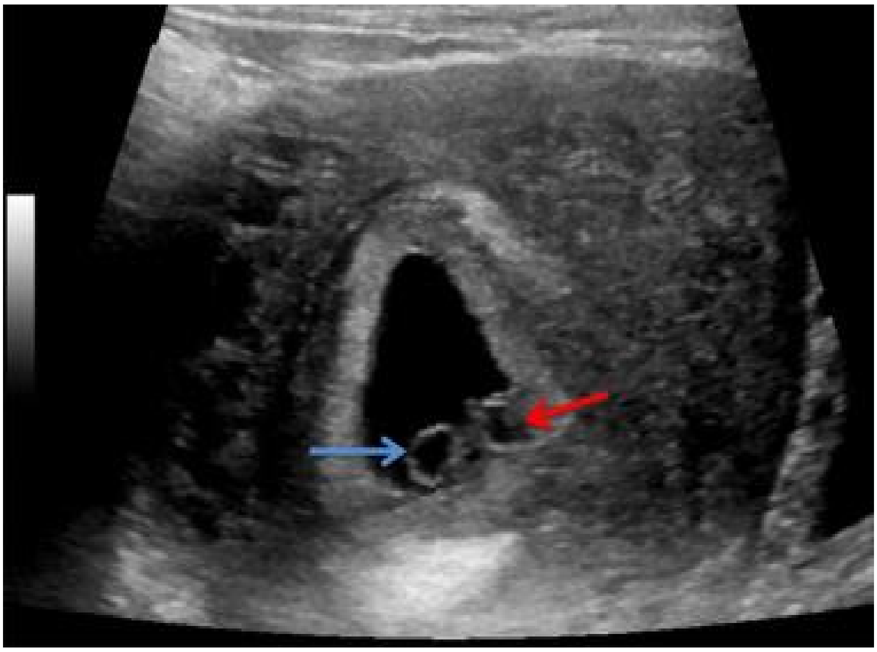

Figure 5. *Real image (blue) and ghost artefact (red) [10].*

Attenuation of sound causes different shadowing artefacts (clean shadowing, partial shadowing and dirty shadowing). For instance, partial shadowing often occurs behind calcifications and stones, if the cross-section of ultrasound beam at the depth of the stones is larger than diameter of the stones. Partial shadowing also appears behind greatly attenuating soft tissues. Another form of shadowing, dirty shadowing, appears behind gas collection. The pulse reflected off gas, interacts with the boundary surface in front of the gas surface and then reflects back to the transducer. This phenomenon produces low-level echoes, which appears as dirt in the ultrasound image. [10]

Reflection between an extremely reflective boundary surface and transducer or between reflective boundary surfaces, such as metallic objects, air pockets or calcified calcium deposits leads to multiple back and forth reflection. This phenomenon is known as a reverberation artefact, often called ‘comet-tail’ [4]. In comet-tail, the sequential echoes are formed as evenly spaced echogenic bands, so individual echoes cannot be detected [10]. Highly reflective surfaces can also relocate the real image so, that a virtual image can be seen on the other side of the surface. For instance, diaphragm/lung interface acts like a mirror, because gas reflects almost 100% of the sound. Likewise, because of reflection, a real image in the liver could be seen where the lungs are situated [10].

Other electronic devices can cause electronic interference, which will disturb the ultrasound image. This interference appears, for instance, when a non-dedicated electrical outlet is used and another electric device is turned on. In this case, electric signals may penetrate the ultrasound system. The artefact forms spikes into the ultrasound image, as seen below in figure 6.

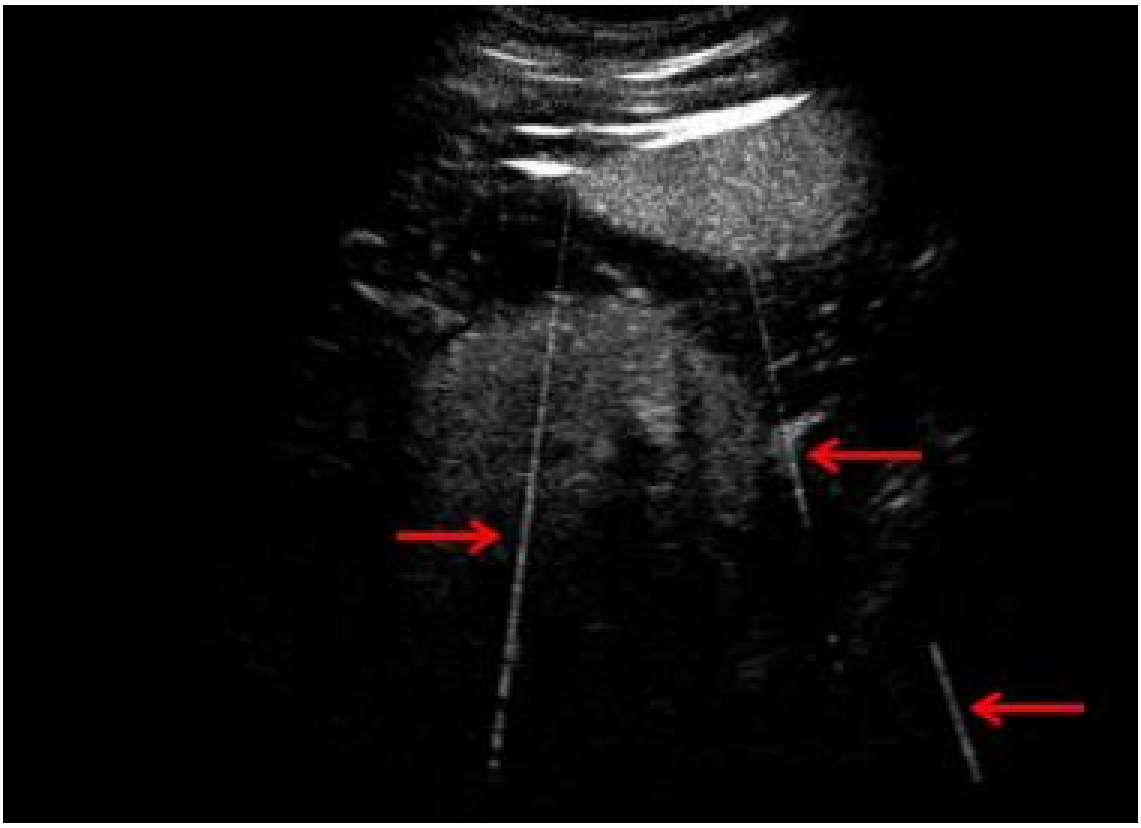

Figure 6. *Spiking artefact caused by electronic interface [10].*

Other artefacts are side lobes and grating lobes, which often occur with urinary bladder, gallbladder or needle biopsy [10]. Side lobes appears from the expansion of the piezoelectric elements perpendicular to the main beam and emission of ultrasound energy occurs. Grating lobes originates from the division of a smooth transducer surface into several small elements. This lead to misdirection of the energy, which creates ghost images of off-axis high contrast objects. Grating lobes can be minimized, by using closely spaced (less than one-half wavelength) elements. This artefact occurs more easily in linear arrays, because of the larger spacing of the individual elements [4].

2.6 Quality assurance of ultrasound imaging

To maintain accuracy, performance and safety of ultrasound imaging, researches recommend to execute quality control tests regularly [6]. Despite the recommendations, organised and regular quality assurance is often neglected entirely. The main reason for the negligence is probably the lack of proper quality assurance requirements. Another reason may be that ultrasound devices are relatively inexpensive, while the cost of ultrasound maintenance including quality assurance, is high [11]. In addition to these two reasons, ultrasound quality assurance is often neglected because ultrasound users do not have sufficient capability to recognize faults in the system and thus overlook them. Because of the lack of proper ultrasound quality assurance, there are many faulty ultrasound systems in daily clinical use. These defective ultrasounds can lead to remarkable risk of misdiagnosis [12].

According to a research article, it is suggested that a basic level of quality assurance should include checking ultrasound system elements that are not disposed to rapid technological change but can be harmful to the ultrasound system. These elements are, for instance, physical damage, signal loss between the connections of the system and crystal elements, and light sources in the display monitor fadinge with age. In addition, disinfection, gel ingress or cleaning chemicals may damage the system and Doppler examinations may be inaccurate due to error with probe and software [12].

In addition to the detection of visible faults, it is also necessary to test the image parameters, with tissue-mimicking phantoms. These phantoms are designed to have the same attenuation, backscatter values and velocity of sound as the average soft tissue in the body (1540 m/s) [4]. For instance, in CIRS overall ultrasound phantom model 040GSE, the tissue-mimicking material is Zerdine solid elastic hydrogel. The main parameters that can be measured with typical basic ultrasound phantoms are uniformity, depth of penetration, beam profile, vertical distance measurement, horizontal distance measurement, axial and lateral resolution, contrast resolution, grayscale contrast sensitivity, elasticity sensitivity and dead zone assessment. [13]

Figure 7 shows an image of CIRS overall ultrasound phantom model 040GSE with different testing targets.

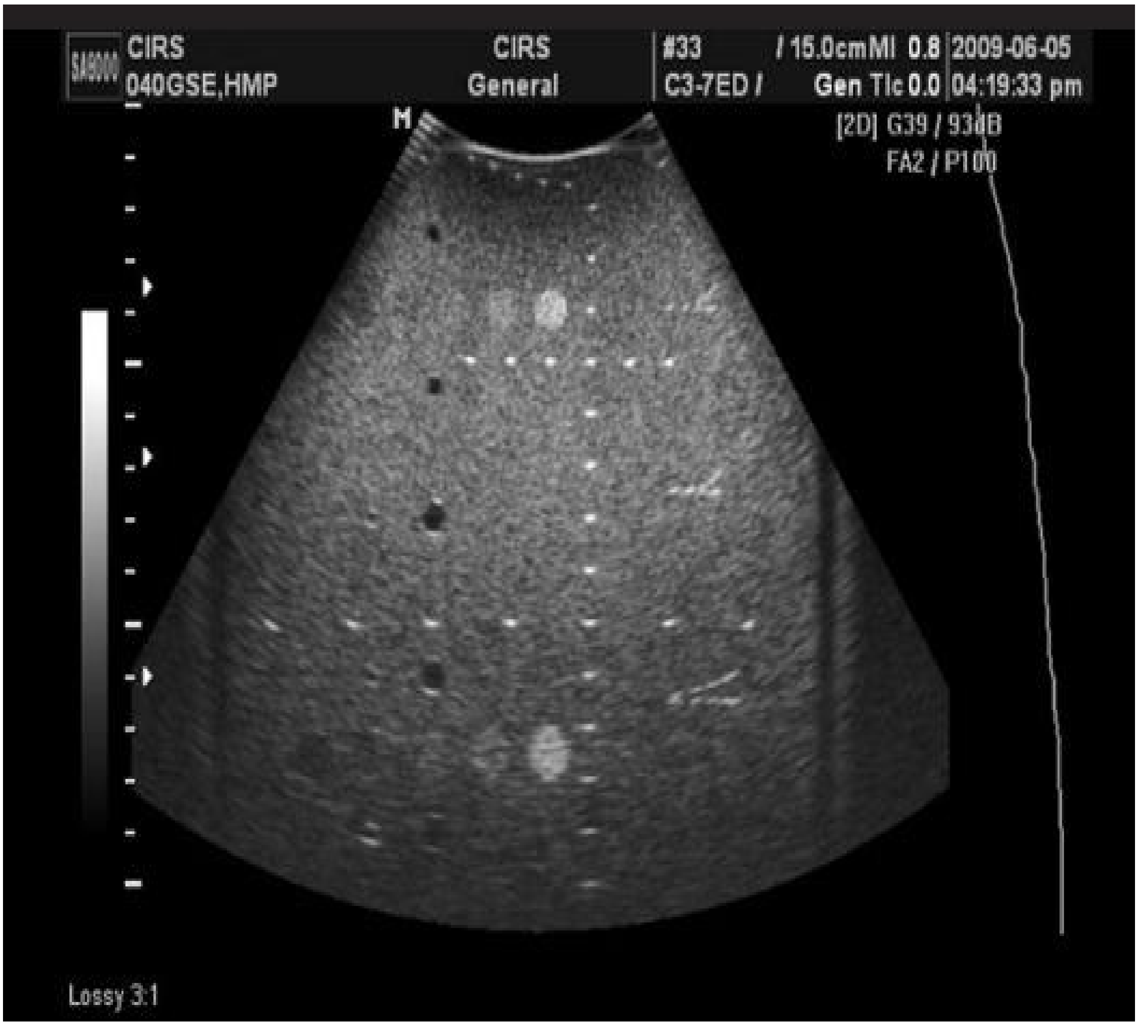

Figure 7. *Different testing targets in CIRS ultrasound phantoms [13]*

Furthermore, there are specific phantoms for Doppler. Cammex 1425A LE Doppler Flow System tests both Doppler and B-mode ultrasound systems. With this phantom it is possible to measure the following indicators: maximum signal penetration, channel isolation and directional discrimination, and flow rates visibility for various angles and beam directions and operating modes. The phantom can be connected to an electronic flow control system, with five programmable test programs and five pre-set pulse flow patterns. [14]

Quality assurance of ultrasound devices is a developing field. One example of this is UltraiQ quality assurance software tool for ultrasound transducer. Every test study of the ultraiQ indicates that reproducibility of the measurements is excellent when using the software. In addition, the software decreases the impact of user variability of ultrasound QA tests to 1% to 3 %. [15]

In the worst case, malfunctions can lead to incorrect medical decisions and diagnoses. For instance, in Sweden, a congenital heart disease was overlooked because of a defective transducer. This missed diagnosis promoted a study in, which 676 ultrasound transducers were tested with Sonora FirstCall test system. The tested transducers, were in daily use in clinical practice at 32 hospitals in south Sweden. Test results showed that almost 40 % of the transducers were defective and carried out the criteria for the transducer to be changed for a new. The most common faults were delamination (26.5 %) and break in the cable (8.4 %). [16]

In another study, transducer tests, phantom measurements and visual checks were performed on 135 transducers. According to the Sonora FirstCall test results, 16 % of transducers had malfunctions. Faulty image quality was noticed in 15 % of phantom measurements, and in visual tests 25 % of transducers were detected defective. This study’s results indicate that none of the three tests is sufficient alone. To obtain reliable results, it is necessary to perform all three tests. When all the three test methods were completed for each of the 135 transducers, the number of defective transducers (2 %) decreased significantly. [11]

3. ULTRASOUND IMAGING IN VETERINARY MEDICINE

The history of ultrasound imaging in veterinary clinics started in the early 1960s. Since then, the popularity has increased and now ultrasound imaging is a widely used in veterinary clinics. There are no precise numbers of ultrasound imaging use in veterinary clinics. However, the questionnaire targeted to private veterinary clinics in Finland, 89 % of the answerers were already providing ultrasound examinations, 7 % were not providing that type of examination and 4 % of the answerers said that they might provide ultrasound examinations in the future [17]. In addition, according to Evira's (Finnish Food Safety Authority), the national agenda of animal medical treatment ultrasound device is one of the minimum equipment demands in every provincial small animal on-call duty clinic [18].

Table 2 is presents the number of ultrasound examinations completed in the small animal hospital Viikki during 2011, 2012, 2013 and 2014. The number of ultrasound examinations from all the operations is small. In 2014, only 6 % of all operations completed in the small animal hospital were ultrasound examinations.

Table 2. *Number of ultrasound examinations completed in the small animal hospital Viikki during2011, 2012, 2013 and 2014 [19;20;21;22].*

Operation	2011	2012	2013	2014
Wide ultrasound examination (45-60 min)	223	295	349	382
Ultrasound examination in control visit	125	159	245	203
Succinct ultrasound examination (30 min)	186	116	124	160
Cystosentesis during ultrasound examination	158	111	98	139
Ultrasound examination of the heart	56	73	80	84
Ultrasound guided fine-needle sample	-	66	58	38
Heart ultrasound, control visit	56	47	48	45
Together	**804**	**867**	**1002**	**1051**

Table 2 illustrates, the commonness of ultrasound examinations has increased over the years. In 2011, the number of different ultrasound examinations in the sample was 804. In the following years, that number increased to 867 (2012), 1002 (2013) and 1051 (2014). In 2014, wide ultrasound examinations (45-60 minutes) were performed more than once in a day. [19;20;21;22] In addition to the operations listed in the table 2, ultrasound examination is also included in other operations not mentioned in the annual reports. For instance, ultrasound imaging is often used in diagnosing uterus inflammation or removal of foreign body objects. If one assumes that the number of ultrasound examinations has continued to increase over the years, currently the number would be approximately 1150 ultrasound examinations per year.

Ultrasound examinations are clearly uncommon among large animals (horses and livestock). Table 3 displays the number of ultrasound examinations completed during 2011, 2012, 2013 and 2014 in the horse hospital in Viikki.

Table 3. *Number of ultrasound examinations completed in the horse hospital in Viikki during 2012, 2013 and 2014 [19;20;21;22].*

Operation	2011	2012	2013	2014
Ultrasound examination	6	10	11	13
Gestation identification	4	4	4	5
Ultrasound examination of the heart	2	2	2	2
Together	12	16	17	20

As the table 3 indicates the commonness of ultrasound examinations has also slightly increased over the years in the horse hospital. In 2011, the number of different ultrasound examinations was 12. In the following years, that number increased to 16 (2012), 17 (2013) and 20 (2014).

The advantages of ultrasound imaging are as follows: it is non-invasive; normally general anaesthesia or sedation is not needed, and it is possible to evaluate dynamic functions, for instance vascular system and structures. Disadvantages include devices being surprisingly expensive and the considerable time requirement needed to master ultrasound and to understand the parameters. In addition, veterinarians should be familiar with artefacts and how thee arise because artefacts easily leads to misinterpretation. [23]

Ultrasound imaging is used in many different applications. The main imaging application is gestation identification. Ultrasound imaging is also extensively used to study different soft tissues, for instance the urinary bladder, tumours, liver, kidney and heart of small animals [24]. In addition, ultrasound is used both for small and large animals to examine tendons, ligaments and joints and the margins of bones around the joints [25].

Ultrasound imaging procedures and principles are the same in animals as in human. Normally the same ultrasound device and transducers used for humans can be used for animals. However, the veterinary medicine field is wider. Veterinarians have to be familiar with placement relationships between anatomical structures in different animals and identify breed specific disorders. In addition, veterinarians often work without an assistant, and because of this, restless animals that cannot remain still are a major challenge for image quality. [1]

There is no uniform and clear legislation for ultrasound devices used in veterinary medicine. The safety requirements for ultrasound use in veterinary medicine are established in the medication of animal law (387/2014). The law is adapted to animals regarding the use of equipment and devices. In this law, the equipment used in veterinary medicine means the instrument, device, or material used to dose medicine, diagnose or treat a disease or regulation of vital functions. This law is also adapted in the supervision of the use of this equipment. Evira is responsible of equipment utilization and supervision. Its task is to plan, lead, supervise and develop the enforcement and observance of this law nationwide. In addition, Evira's mission is to organize the education of veterinarians. [26] There is no separate legislation concerning medical devices and equipment used in veterinary medicine because they are mainly the same as those used in human medicine. Therefore, the medication of animal law (387/2014) is equivalent to the law of the Finnish Medical Device Act (629/2010) in applicable sections. [27]

3.1 Preparations

Before ultrasound examination, it is important to do preparation. Preparations can remarkably increase the image quality and diagnostic accuracy of the examination. The most common preparation before an ultrasound examination is shaving the fur over the area of interest. The fur needs to be shaved because the air trapped in the fur amplifies the ultrasound wave conductance, causing disturbances in the ultrasound image [1]. In regions were the fur is thin, it is sufficient to wet the fur with water or alcohol to eliminate air. After shaving the fur, gel is spread on skin surface to ensure good contact with the transducer [25].

Veterinarians normally give animal owners preparation instructions before scheduled ultrasound examinations. Preparation instructions should always be provided when necessary. One common preparation instruction, especially for scheduled ultrasound examination is suggested fasting [1]. Fasting is recommended before ultrasound examinations to decrease the amount of gas in the intestines. Because gas in the gastrointestinal track prevents propagation of ultrasound echoes animal owners are often instructed to fast their animal from six to twelve hours before ultrasound examination [24;28]. However, based on one study, fasting dogs does not improve image quality of specific abdominal organs, such ss the pancreas, portal vein, duodenum, adrenal glands and the gall bladder [28].

Because veterinarians are often work, without an assistant, sedation or anaesthesia is often needed for uncooperative and restless patients [29]. Sedation is frequently used in situations in which the patient is restless and can not stay still during the ultrasound examination. Sedation medicine is normally dosed with a sting to muscles. Intravenous anaesthesia is used in situations, in which stronger pain relief and deeper sedation is needed. For instance, anaesthesia may be necessary when taking fine-needle samples. Short-term anaesthesia medicine is given by cannula to the vein of the front or back leg. Sedation and anaesthesia are always considered individually to make it as safe as possible. In addition, vital functions are monitored constantly during sedation and anaesthesia. For example, the body temperature of sedated or anaesthetised dog decreases easily. Therefore, it is necessary to monitor the body temperature and prevent the decrease with blankets and heaters. [30]

If sedation or anaesthesia is needed, it can sometimes be vitally important to fast the animal. Fasting is recommended before anaesthesia to reduce the amount of stomach contents and especially stomach acidity. Anaesthesia relaxes muscles that normally prevents the stomach's acidic content from moving to the lungs. Emesis (vomiting) during anaesthesia can lead to the acidic content of the stomach harming the lungs. However, fasting before anaesthesia decreases this risk. [31]

3.2 Examination procedure

In ultrasound examination, the location, shape, size and intensity of the echo are evaluated [32]. Normally, ultrasound examinations last about 15 to 30 minutes [33]. Ultrasound examination procedures depend on the animal's anatomical structure and shape. Small animals undergo transcutaneous examinations (through the skin surface), but some examinations for big animals has to be done through the rectum. For instance, the horse uterus lies far away from the skin surface, and therefore, gestation identification is achieved through the rectum.

Typically, ultrasound imaging can be completed without assistant, but with restless and big young dogs, an assistant can hold the patient still. [33] The patient's positions depend on which anatomical object is being imaged. It is necessary to choose the imaging direction so that imaging through bone and lungs can be avoided because these organs reflect a large percentage of the ultrasound beam [32]. For instance, while imaging the heart it is important that the ultrasound beam does not have to pass through the lungs. In abdominal ultrasound examinations, the patient is normally in a supine position in an upholstered and robust underlay (figure 8) [33].

Figure 8. *Typical position of a dog in an abdominal ultrasound examination [33].*

3.3 Device and transducer

Normally, the same ultrasound devices used for humans can be used for animals, although manufactures have specific devices designed for animal applications [1]. For instance, one ultrasound designed for veterinarians is the Sonovet ultrasound, presented in section 2.2. There are many choices in the shape and size of the transducer. In addition, the frequency of the transducer can be adjusted in different ways. To obtain high-quality image resolution, it is necessary to select a transducer and frequency that is most suitable for the anatomical structure to be observed and the examination complete. Normally, the examination is performed using either a linear array or sector array. [18;34]

The higher the ultrasound frequency, the better the image resolution, although high frequencies do not penetrate deeply. A 5 MHz transducer can reach a depth of almost 15 cm, and with a 7 MHz transducer, objects with a depth greater than 10 cm can be seen clearly [24]. For instance, small cats and dogs can be explored with a linear array transducer and a frequency of 10.0 MHz. The best transducer for medium-sized dogs is a 7.5 MHz linear array or 5.0 MHz or a less curvilinear array if the examination is performed on tissues near the skin surface [1].

In a linear transducer, the image is displayed as a square on the screen [34]. A linear array is suitable in situations in which the object is near the transducer. The image is equally wide in every location and is as a crosscut from the object in the direction of the transducer. [24] In a sector array, the image is narrow near the transducer but widens deeper into the tissues. The sector array is useful in situations, in which examination has to be performed in narrow slots, such as the ribs and intestines. [24] In addition to these two transducers, a curved array transducer can be used. The image of this array is similar to a sector array, but provides a wider image near the transducer [7].

In figure 9, an image of canine liver examined using curved array transducer (A) and an image of feline stomach examined with a linear array transducer (B) are displayed.

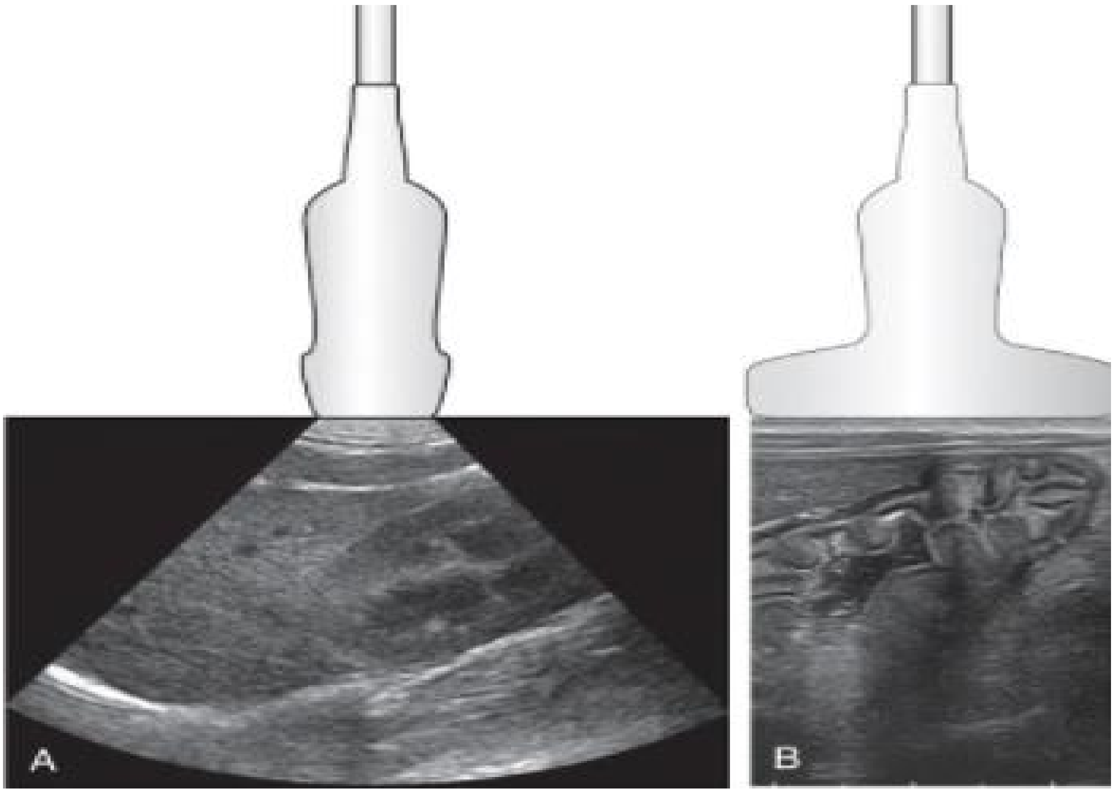

Figure 9. *Shape of the image by using curved array transducer (A) and linear array transducer (B) [34].*

The quality and accuracy of ultrasound imaging is dependent on the adjustment of parameters and selection of diagnostic imaging mode. In Sonoscape – a portable ultrasonic diagnostic system, a veterinarian can adjust the following parameters: frequency, dynamic range, gain, grayscale curve, left/right invert, up/down invert, image rotation angle, depth, line density and zoom factor. The device also has ready-made diagnostic modes for different applications, from which veterinarian can choose the most suitable for aa given procedure [8]

In figure 10, below, displays the keyboard and different selection buttons of the SonoScape ultrasound device.

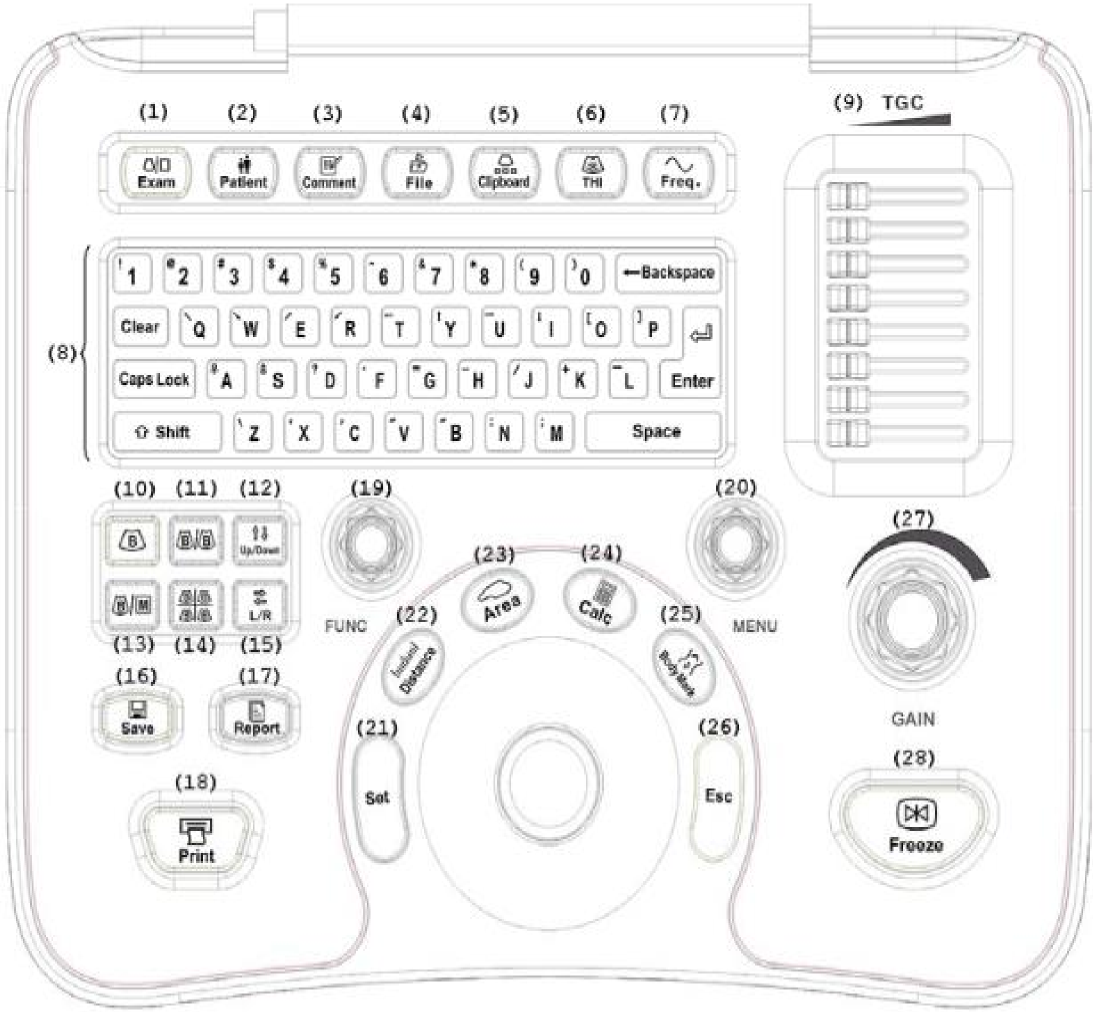

Figure 10. *Keyboard of the SonoScape ultrasound device [8].*

Button number one (exam) allows the user to select a specific exam mode for the transducer. With TGC (time gain compensation) sliders, the ultrasound echo gain can be adjusted in depth. Gain dial (number 27) adjusts the brightness in B-mode ultrasound image. Button number 28 (freeze) stops the image for close examinations. By adjusting depth, the displayed image field can be changed. The depth should be adjusted to the minimum requirement, to allow every structure of interest to be seen. The image resolution suffers, when the depth is increased. Dynamic range means the ratio between the smallest and largest signal in the ultrasound image and has an impact on image contrast. With keyboard selections, it is also possible to measure depth, and area and freeze the ultrasound for close examinations. [8]

3.4 Applications

Ultrasound imaging is used in many different applications, such as to examine the uterus, urinary bladder, abdomen and heart and blood vessels of small animals [23;24].

3.4.1 Abdomen

One of most common ultrasound applications is examinations of different abdominal organs, such as the liver, kidney, gallbladder, spleen, pancreas, stomach and gastrointestinal tract. The location of some abdominal organs complicates the ultrasound examination. For instance, the pancreas lies deep in the abdomen and is surrounded by gas-filled organs (stomach, duodenum and colon). Figure 11, below, illustrates the position of different abdominal organs in the canine digestive system.

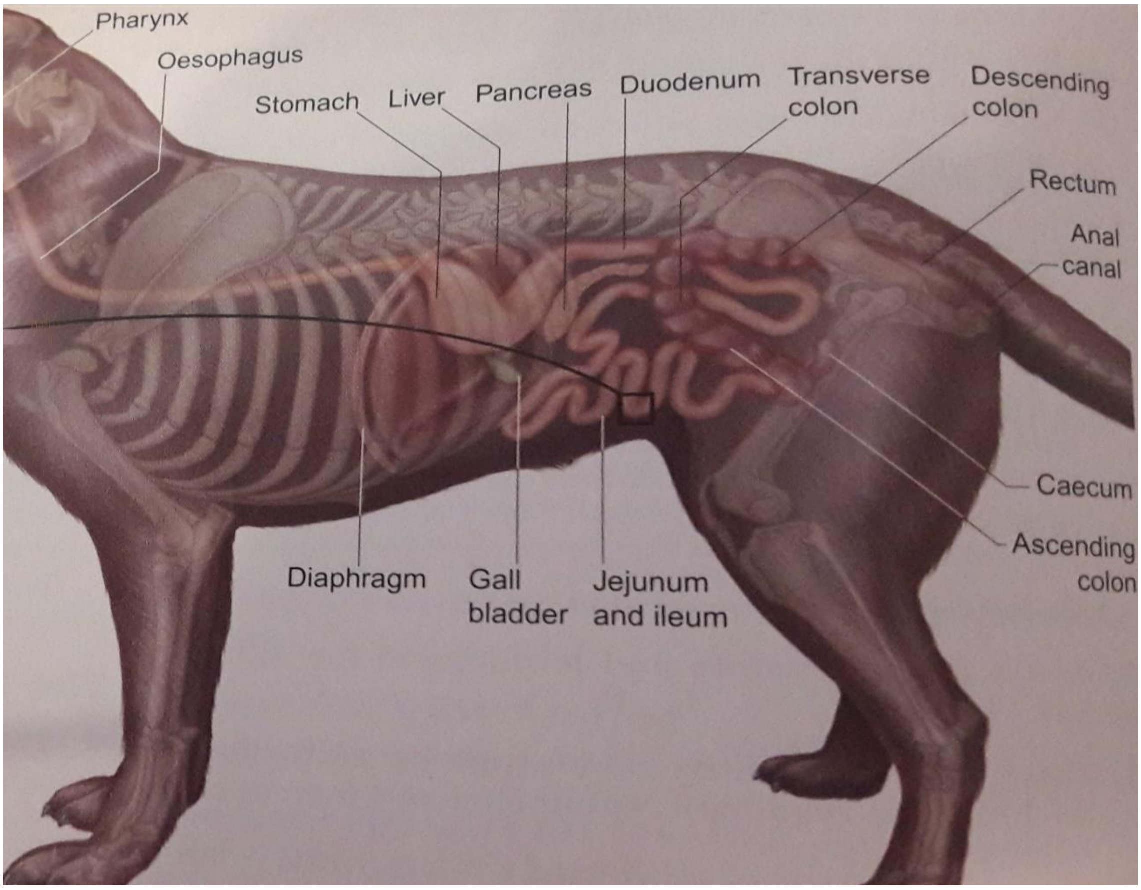

Figure 11. *Position of different abdominal organs (gallbladder, spleen, pancreas) in the canine digestive system [35].*

Normally, an abdomen examination can be performed anywhere on the abdominal wall with the animal in the dorsal position. Cats and small to medium dogs can be imaged with a 5 to 10MHz transducer and large dog breeds requires as 3.5 to 5 MHz transducer. However, for superficial areas of the stomach, a 7 to 10 MHz sector transducer is suitable and provides a better image resolution for examinations for cats and small-to-medium-sized dogs. [23]

Along with different abdominal disease suspicions, abdomen ultrasound is often used to examine foreign bodies. Foreign bodies in the intestines easily causes blocks, which can be life-threatening. To examine the small intestines, a 7.5 MHz transducer is most suitable. Foreign bodies are identified from the ultrasound image either through a strong reverberation interface or the dead zones they are causing. Foreign bodies can also be noticed from the expansion of the small intestine cavity and changes in the mobility of the intestines. [36]

Examinations of the gastrointestinal tract (stomach, duodenum, jejunum, ileum, cecum and colon) is difficult because of gas and food [1;36]. Gas in the gastrointestinal tract causes dead zones [36]. To decrease the amount of gas in the gastrointestinal tract, fasting is often recommended before examinations to obtain better visualization and the correct diagnosis [1].

3.4.2 Urinary bladder

The urinary bladder is often examined because of symptoms indicating urinary tract infection or a history of bladder or kidney stones and unexplained retention of urine. Normally, the most suitable transducer for urinary bladder examinations is 7.5- to 10-MHz curve-linear transducer. The animal should be placed in dorsal recumbency and the whole urinary bladder should be examined through both the transverse and longitudinal planes. [37]

Ultrasound imaging is suitable for the urinary bladder based on the contrasts between the echogenic urinary bladder wall and urine. Therefore, the urinary bladder must be urine-filled in ultrasound examinations. [32] Thus, veterinarians recommend pet owners to carry the animals to clinic, to ensure there is urine in the bladder. [37] In addition to normal urinary bladder examinations, ultrasound is also used to guide cystocentesis, which means taking a urine sample [32].

3.4.3 Uterus

The main reason the uterus is imaged is gestation identifications. Another common reason is dubitation of uterus inflammation. Ultrasound examination of the uterus is typically performed with the animal in a standing position. To avoid the harmful effect of intestinal gas, the lateral aspect of the caudal abdomen is sometimes used. The most appropriate transducer for uterus examinations is 7.5 MHz, except for giant breeds such as the Great Dane. [23]

In uterus inflammation, the mucous membrane of uterus is thickened, and there might be accumulated secretion inside. Normally, the uterus of small animals cannot be seen in ultrasound if there is nothing inside it. However, when inflammation occurs, there is secretion inside the uterus, which is seen as black or as grey lines in the ultrasound image [24].

The gestation checks of dogs and cats are usually performed four to five weeks after the service. Normally, the number of puppies is also estimated at the same time. Although it is not totally accurate, because the calculation is based on the number of fetuses seen at the same time in the ultrasound image. [24]

3.4.4 Heart and blood vessels

Ultrasound imaging is often used to examine heart and blood vessels and evaluate cardiac disorders. Blood flow, velocity and pressure of cardiac valves can be examined with Doppler ultrasonography. In Doppler examinations, the animal is normally in lateral recumbency, and the beam directions should be at 180 degrees. [23]

In Doppler imaging mode the direction of the flow is coded with different colours. In addition, with colour flow Doppler possible turbulences in the blood flow can be examined, as illustrated in figure 12. This turbulence is often a sign of a failure in a heart valve or a problem somewhere in the heart. [24

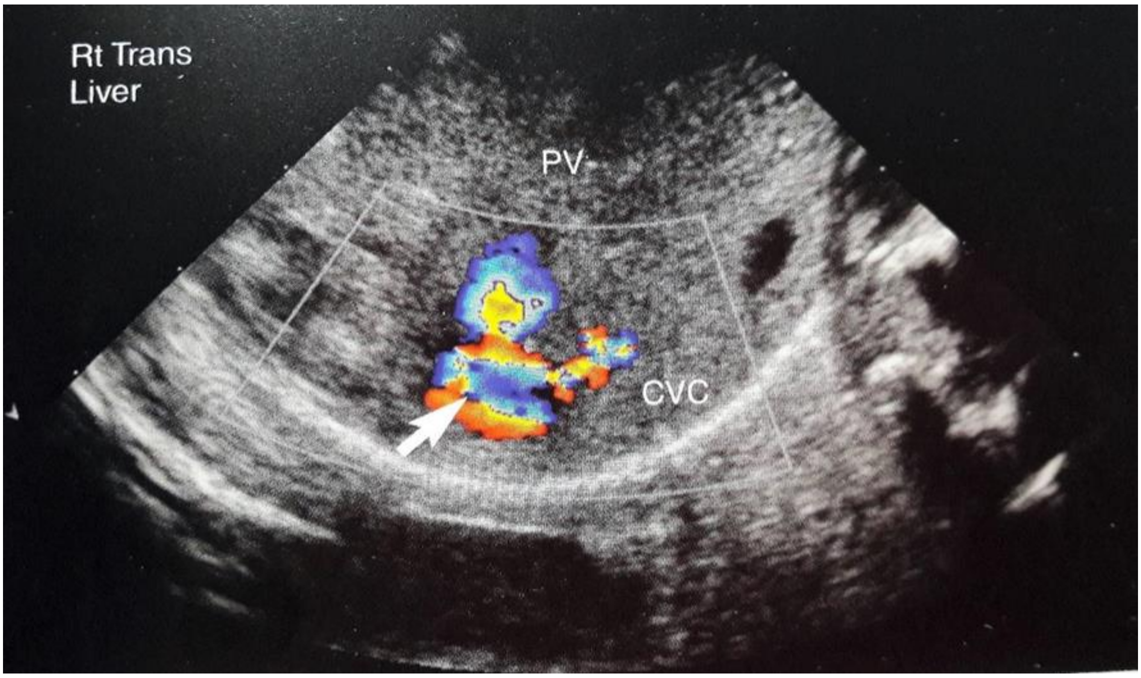

Figure 12. *Turbulence in the blood flow seen in liver [18].*

Abbreviations in the figure 12, refers to blood vessels connected to liver. PV means portal vein and CVC caudal vena cava [23].

In addition to Doppler, different cardiac measurements and calculations of cardiac functions can be completed using M-mode. The most suitable transducer for high-quality images quality and resolution is 5 to 7.5 MHz for most dogs and cats, although large dogs may need a 3 to 5 MHz transducer. [23] For instance, with the M-mode cursor's thickness, a normal outline and position in relation to other structures of valve leaflets can be examined. One example of a measurement is fractional shortening, which describes the contractility of the ventricle expressed as a percentage.

Fractional shortening (FS %) can be calculated with equation 23:

$$FS\ \% = (LVIDd - LVIDs) / LVIDd \cdot 100 \tag{23}$$

where LVIDd is the left ventricular internal dimension (diastole) and LVIDs is left ventricular internal dimension (systole). Fractional shortening normally occurs from 28% to 45% in dogs and from 29 % to 55 % in cats. Some giant breeds may have a value as low as 22%. [23]

3.4.5 Ultrasound guided fine-needle samples

Fine-needle biopsy samples are important tools for veterinary clinicians when taking cytologic samples. The benefits of fine needle biopsy samples are as follows: the technique is quite simple, accurate and rapid; low risk of complications; it is minimally invasive; and sedation is not usually needed. There are two different fine-needle biopsy techniques: fine-needle aspiration and fine-needle fenestration. [38]

In the fine-needle aspiration technique, the needle is fastened to a syringe. Before the needle is set in the tissue, negative pressure is applied to the syringe. Then, the needle is extracted from the syringe, which is filled with air to improve the expulsion of the tissue sample onto the slide. The fine-needle fenestration method is based on capillary action. The veterinarian will hold the needle between the thumb and forefinger and rapidly insert it back and forth into the tissue. Afterward, the syringe, prefilled with air, will be attached to expulse the tissue material onto slides. [38]

The tract and movement of the needle is often observed with ultrasound to avoid errors. Ultrasound guidance can ensure the needle strikes the correct locations and does not disable other tissues. The fine-needle can be introduced to tissue either free-hand or by using o biopsy guidance in the ultrasound device. In a biopsy guidance program, the track of the needle can be continuously seen on the screen between two navigation dots. For a maximum visibility, the needle should be inserted at a 90 degrees angle to the tract of an ultrasound beam. Sedation is often needed to ensure that the animal does not move during the procedure. [23]

3.5 Image quality

Image quality is dependent on the user, transducer, device gain settings and patient preparations. The ultrasound user's experience and knowledge has a major impact on image quality and the benefit of the examinations. It is necessary to identify radiological errors and understand how they might impact future patient treatment. [39] Although diagnostic imaging is widely used and a beneficial diagnostic method in veterinary medicine, it is not 100 % accurate and it does not always benefit the animal as it is supposed to. Typical problems concerning diagnostic accuracy are false positive diagnoses, detection of incidental findings and over-diagnosis. Image quality and diagnostic accuracy in veterinary medicine had been studied little, and there is demand for new clinical studies to help veterinarians provide optimal animal care. [40] The next paragraphs introduce some diagnostic accuracy researches.

In Brazil, 105 cats and dogs participated in an ultrasound accuracy study. First the patients were examined using ultrasound within 12 hours after they went through a surgical procedure. After the examination, the results of ultrasound and surgical procedures were compared to discover whether the surgical findings had been correctly recognized by ultrasound examination. According to the results, over 80 % of cats and dogs were accurately diagnosed using ultrasound imaging. However, there were 17 (16.2 %) mistakes in ultrasound diagnosis. Of these errors, 10 of 17 mistakes was caused by cognitive errors, meaning misinterpretation of ultrasound imaging findings; five of seventeen errors were classified as inevitable errors, which denotes that abdominal imaging results were absent or hidden so extraordinarily that a correct diagnosis would not be expected; and two of seventeen errors were multifractional, or a combination of cognitive and perceptual errors. Perception mistakes originated from the veterinarian's failure to recognise abnormalities on the image. [39]

Another study tested how various patient and image factors, such as age, gender, body weight, body condition score, patient compliancy and image quality affect the detection of select canine abdominal organs. The same study also investigated the effect of sedation and fasting. Of a total 100 dogs, 71 were fasted before ultrasound for 12 hours and the remaining 29 dogs were not fasted. Sedation was needed for 13 dogs, and the remaining 87 dogs were examined without sedation. Based on the results, there is clear difference in the dog's obedience and behavior with and without sedation. With sedation, the compliance was evaluated as 'good' or 'compliant' 12 times (92 %) but, without sedation, this percentage dropped to 61 (53/87). In addition, study results indicated that gastrointestinal gas and obesity has negative impact on examinations of the duodenal papilla and pancreas. The visibility of the duodenal papilla was 42 % and 60 % for pancreas. The visibility of the jejunal lymph nodes were only 51 % and medial iliac lymph nodes 54 %. However, the study did not find a reason for this difference. [41]

In a third study, 137 dogs participated in cross-sectional research, that aimed to evaluate the diagnostic accuracy of ultrasound imaging to predict the position of hepatic masses in dogs. First, the location of the lump was evaluated with an ultrasound, and afterward, the results were compared to the location identified by surgery. Based on the results, the location of the hepatic mass was correctly identified with an ultrasound in 51.8 % of the dogs. In the rest of the cases (48.2 %), the location of the mass was predicted incorrectly or could not be determined. Deeper analysis of the findings revealed that localization of the right division of the liver was more accurate than localization of left division. In the right division, 58 % of solitary hepatic masses were correctly localized, 8 % were incorrectly localized and 8 % could not be localized at all. The corresponding percentages of left division were 55 % of the masses correctly localized, 13 % incorrectly localized and 32 % not localized. Overall, the study findings indicate that ultrasound was a specific but insensitive method for locating hepatic masses. In addition, this research proved the existence of other coincidental liver pathology and the true location of the hepatic mass had an impact on identification accuracy. [42]

4. MATERIAL AND METHODS

The material for this thesis was collected from a survey. The aim of the survey was to gather information from veterinary clinics in Finland assessing the use of ultrasound imaging. A questionnaire, containing 11 questions, was made available online and sent to 160 veterinary clinics in Finland. The criteria for veterinary clinics selected for this survey was as follows: the clinic could be found by using Google maps and an e-mail address was present on the clinic's website. By the deadline, 58 answers were received. The questionnaire was internet-based and was performed during December 2017.

The survey was half structured, including both multiple choice and open-ended questions. This way the questions in the form were not too restrictive, and veterinarians also had an opportunity to answer freely. The questionnaire was tested beforehand with five people. Based on feedback from of test participants, questions were modified to be understandable and unambiguous.

The questionnaire is presented in its entirety in attachment B. The aim of the first question was solely to determine, how many veterinary clinics use ultrasound imaging. Participants who did not use ultrasound, returned the survey after answering this question. The second question asked the participant's specialization and graduation year. The purpose of this question was to define, whether graduation year or profession have an impact to other variables. For instance, ultrasound education included in veterinary studies may have decreased over the years or the answers may differ depending on specialty.

The first two multiple choice questions asked how often and in what examinations and applications ultrasound imaging was used and in that veterinary clinic. The next three multiple choice questions (5-7) related to learning, training and practice of ultrasound imaging. The aim of these questions was to find out for example, how many hours veterinarians had in theoretical and practical learning before starting independent ultrasound imaging and what they consider their primary learning method. The last, multiple choice question asked whether quality assurance was performed and how often.

The survey included two open-ended questions. The first asked what kind of preparation instructions animal owners were given before ultrasound examinations. To help the participants understand the meaning of, 'preparation instructions', an example was given: 'when urinary bladder is ultrasound examined, the bladder should be as full as possible'. The other open-ended question asked veterinarians what they consider as the greatest challenges in ultrasound use.

Survey answers are elaborated in chapter 5, where the answers to the survey are reviewed and tabulated. For better visualization of the answers, some statistical diagram and tables was created with Microsoft Excel. Open-ended questions were first reduced and afterward divided into four main categories, then into a further 16 subcategories. For example, the subcategory 'insufficient and diminutive ultrasound education' was included in the main category 'the use of ultrasound'. This subcategory contained answers such as 'There are not enough courses in university', 'Employer does not invest in education' and 'The use of ultrasound device and interpretation of the image are not educated at the university'.

5. RESULTS

By the deadline, 58 answers were received. From those 58 answers almost all 56 (96.6 %) indicated they use ultrasound, and only two (3.4%) do not use an ultrasound device (figure 13).

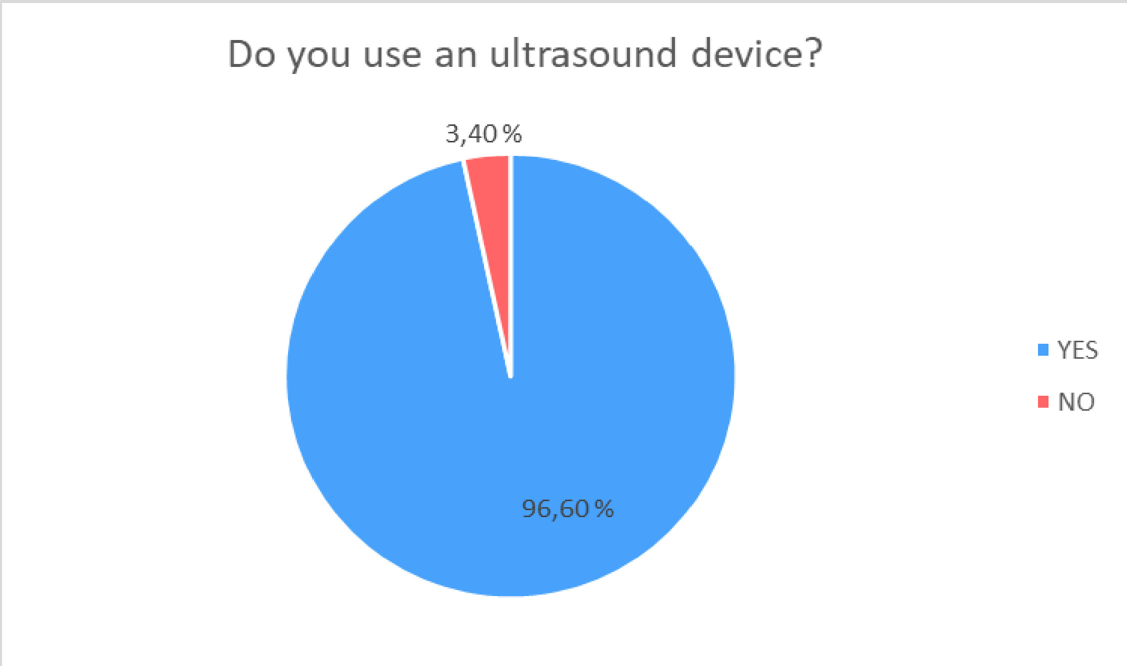

Figure 13. *Distribution of the use of ultrasound imaging.*

Most veterinarians (49/56) who used ultrasound were licentiates of veterinary medicine. Four of the 56 respondents were specialized veterinarians and one was a doctor of veterinary medicine. Two respondents did not state their specialization or graduation years.

The mean graduation year of veterinarians (n=54) was 2006, but in this chapter, the median graduation year (2009) is used as a separation criterion.

5.1 Typical applications

The survey's second multiple choice question dealt with ultrasound imaging applications. The average number of different applications ultrasound was used for is 6.4. As figure 10 presents, the most common ultrasound imaging applications were gestation checks and detection of uterine inflammation. All the respondents used ultrasound at least for these two applications. The next most common applications were different urinary bladder disorders (96.4%), abdominal examinations (91.9 %) and examinations of tumours (80.4 %). General purposes of ultrasound use are also taking ultrasound guided fine-needle (biopsy) samples (42.9 %) and examining eyes (19.6 %), hearts (33.4 %), blood vessels (23.2 %), tendons (25 %) and muscles (16.1 %). Other single answers of ultrasound application were examinations of thoracic cavity (1.8%), examination of ovaries (1.8 %) and ultrasound examination of cryptorchidism (1.8 %).

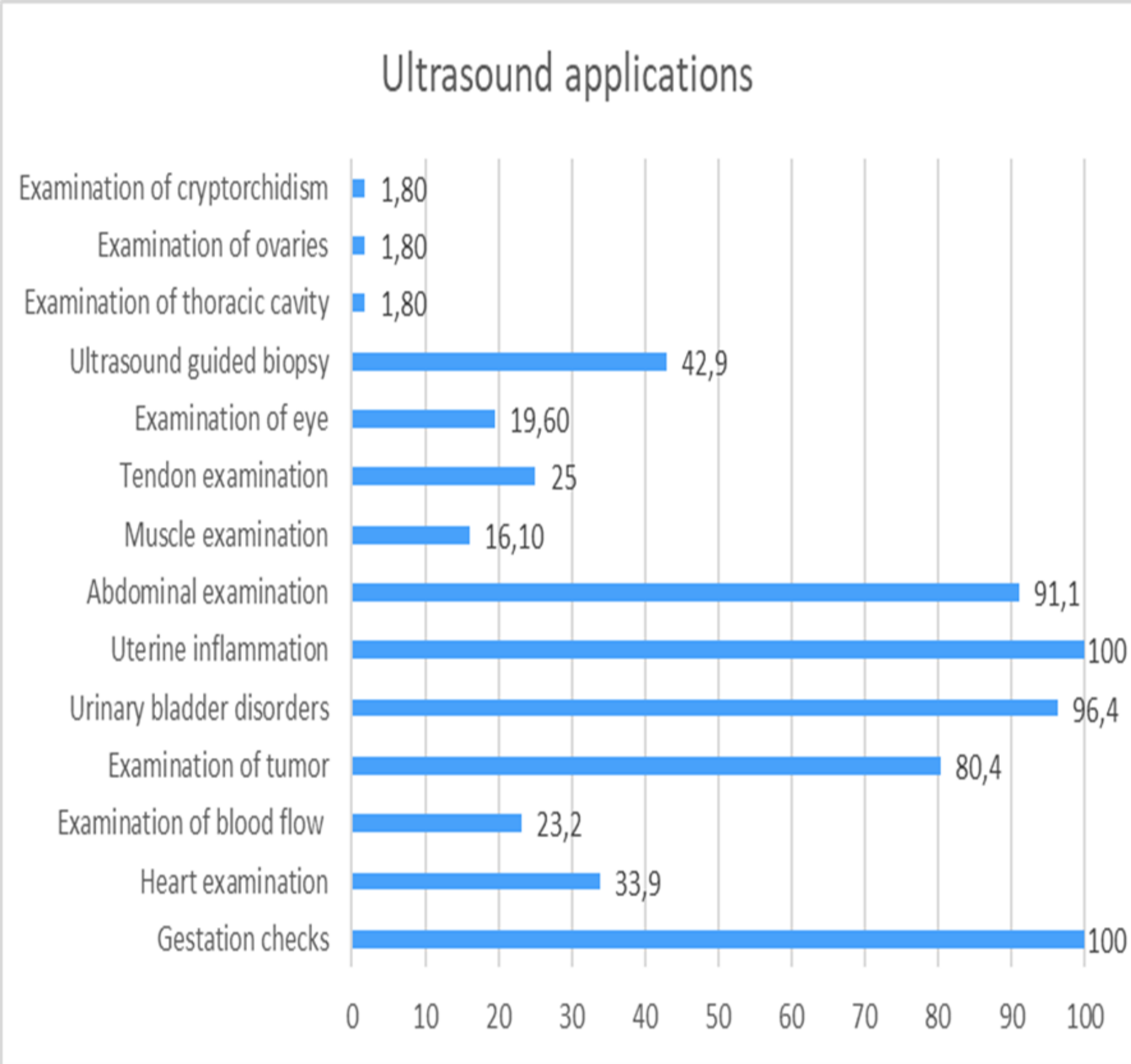

Figure 14. *Different applications of ultrasound.*

Based on the results, there is correlation between the primary learning method and number of different ultrasound applications. Veterinarians whose primary education method was veterinary studies, used ultrasound in less examinations. The average number of applications were only 4.8. On the contrary, the corresponding values for veterinarians who took an additional ultrasound course were 7.0 and 8.0 for those respondents, whose primary learning method was practical training. According to the results, there was also difference in the answers based on specialization. Specialized veterinarians were more educated and familiar with different applications of ultrasound; the average of different applications for these respondents was 7.8.

These results indicate there is an observable difference when the graduation year and different ultrasound applications were compared. Veterinarians graduating before 2009 used ultrasound, on average, in 6.8 different applications, whereas veterinarians graduated in year 2009 or after used ultrasound in 5.9 different applications. Figure 15 illustrates the impact of graduation year on the number of ultrasound examinations.

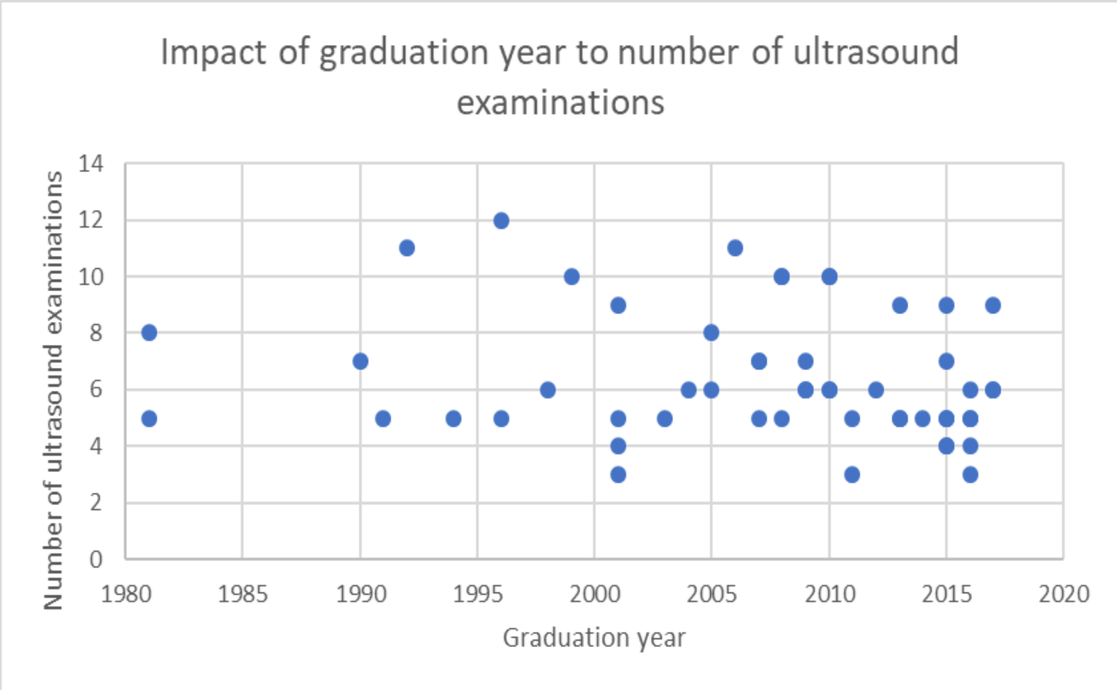

Figure 15. *Impact of graduation year in number of different ultrasound examinations.*

5.2 Commonness of ultrasound imaging

The survey's fourth question evaluated the commonness of ultrasound imaging. According to the results, 11% of veterinarians used ultrasound for at least for one in five patients. The majority of the respondents (33 %) used ultrasound at least one in ten patients or at least one of fifteen patients (31 %), and 16 % used ultrasound at least for one in twenty patients. Only a minor (9 %) portion of the veterinarians used ultrasound less often than for one in twenty patients. The distribution of the commonness of ultrasound imaging is depicted in figure 14.

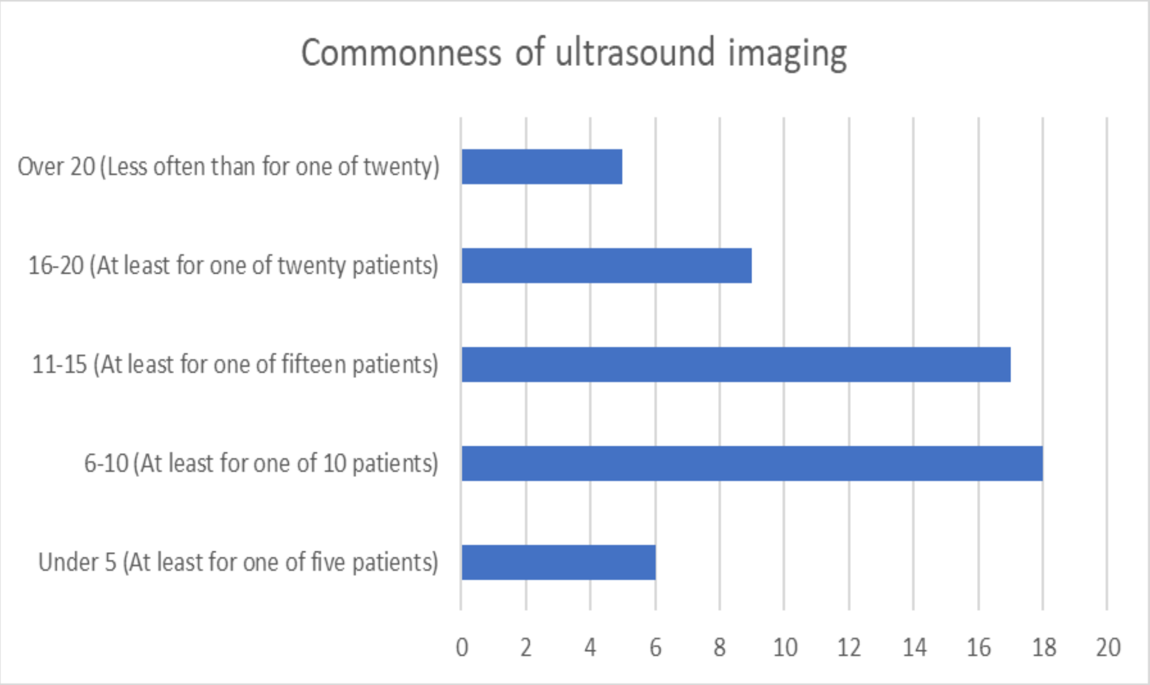

Figure 16. *Commonness of ultrasound imaging – how often ultrasound examination is completed.*

5.3 Learning

Survey questions 5 through 7 of the survey, dealt with learning to use the ultrasound device. Question 5 asked what veterinarians thought their primary learning method was. Figure 17 displays the distribution of primary learning methods.

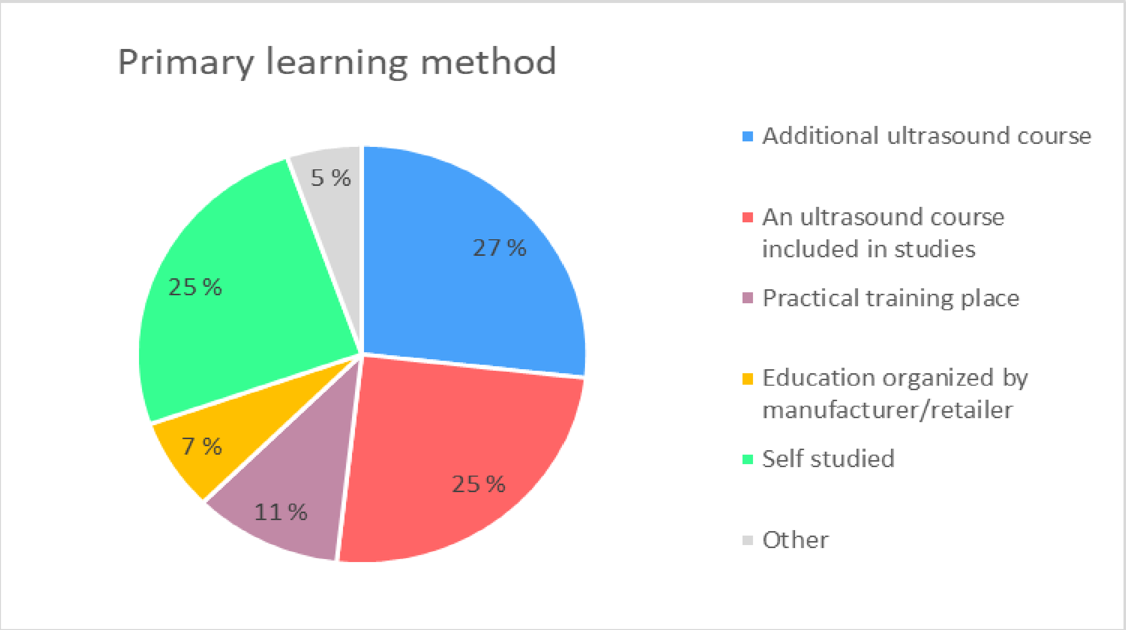

Figure 17. *Distribution of primary learning method.*

As illustrated in figure 17, the main primary learning method, was an additional ultrasound course (27%). The next common methods were self-studying (25 %) and an ultrasound course included in studies (25 %). More uncommon learning methods were practical training place (11 %) and education organized by manufacturer or retailer (7 %). The three single answers (5 %) were “an ultrasound course”, “all of the answers/methods above-mentioned” and “while working in department of diagnostic imaging”.

According to the survey results there is also difference in primary learning methods when comparing graduation years. Figure 18 below illustrates the difference between of primary learning methods when comparing graduation years.

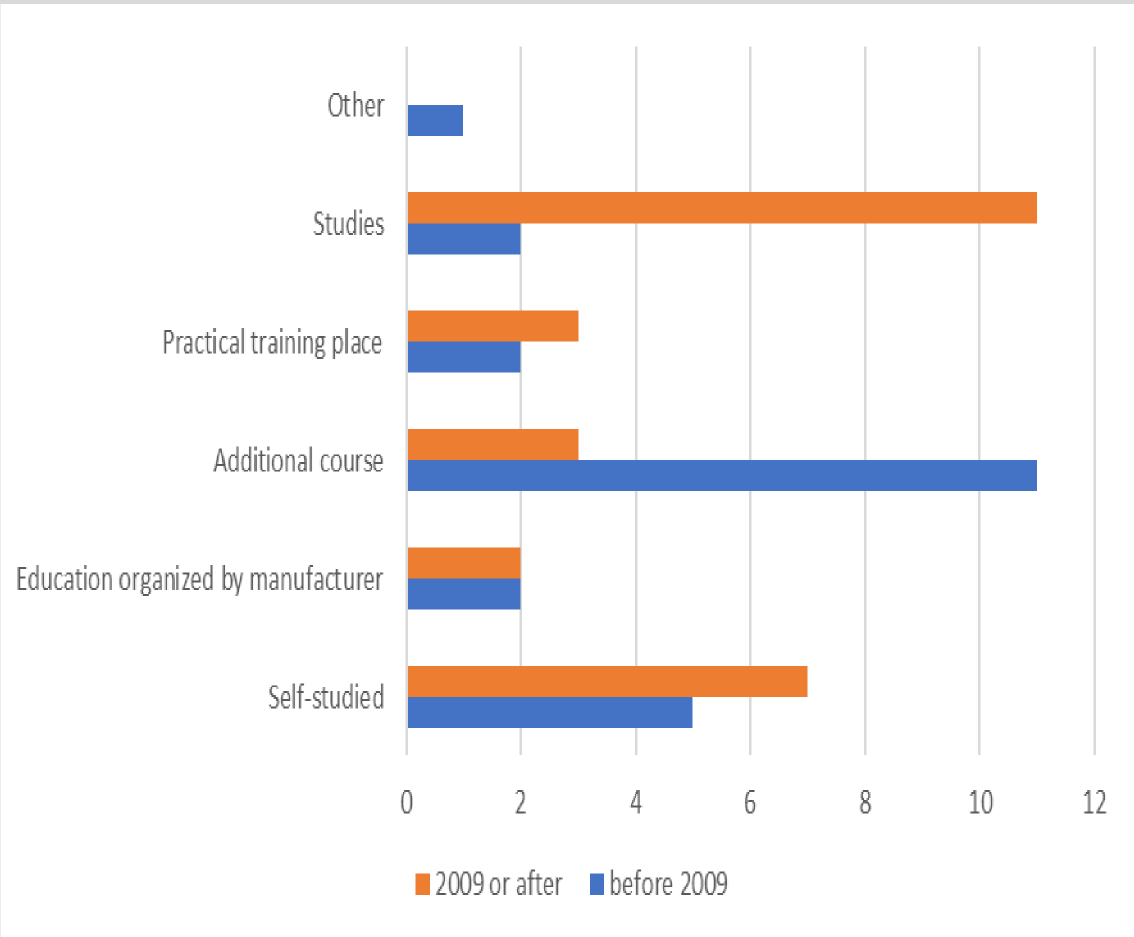

Figure 18. *Impact of graduation year on primary learning method for ultrasound imaging. veterinarians graduating before 2009 are presented in blue and veterinarians graduating 2009 or after are presented in orange.*

The most common primary learning method (n = 11) for veterinarians graduating before 2009 is an additional ultrasound course. Veterinarians graduating 2009 or after mostly learned to use ultrasound through their studies (n = 11) or by self-studying (n = 7).

Survey questions 6 and 7 of the survey asked the number of theoretical and practical learning hours before starting independent ultrasound examinations. Based on the answers, all veterinarians had variety of theoretically and practical learning hours before starting independent ultrasound examinations. The dispersion in the number of learning hours is large. The minimum theoretical and practical learning hours mentioned in the answers was zero, while the maximum learning hours mentioned was 150 (theoretical) and 100 (practical). The average of the learning hours were 17.44 for theoretical and 10.84 for practical. As depicted in table 4, there is clear difference between learning hours compared to primary learning methods.

Table 4. *Theoretical and practical learning hours, before starting independent ultrasound examinations.*

Primary learning method	**Theoretical**	**Practical**	**n**
Additional ultrasound course	18,75	18	15
An ultrasound course included in studies	13,4	5,30	14
Practical training place	23,75	7,25	6
Education organized by manufacturer/retailer	66,67	41,67	4
Self studied	7,21	2,5	14
AVERAGE	17,44	10,84	53

For instance, veterinarians who acquired knowledge from education organized by manufacturers or retailers had noticeably more learning hours than those who did not. The average of theoretical education hours was 66.67, and the average of practical hours was 41.67. On the contrary, veterinarians whose primary learning method was an ultrasound course included in studies or self-studying had limited learning hours. The averages of theoretical and practical learning hours for an ultrasound course included in studies were 13.4 and 5.3, respectively. The corresponding hours of veterinarians who has self-studied were only 7.21 and 2.5, respectively. In additional ultrasound course, the learning hours were 18.75 and 18 and for practical training place 23.75 and 7.25.

According to the results, there is also a difference in theoretical and practical learning hours when comparing graduation years. The averages of theoretical and practical learning hours of veterinarians who was graduated before 2009 were 23.57 and 15.80, respectively. Veterinarians graduating in 2009 or after had an average of 17.61 theoretical and

10.52 practical learning hours. Based on these answers, the number of learning hours has decreased over the years.

Minor theoretical and practical learning hours and insufficient ultrasound education were also mentioned several times as a major challenge in one open-ended question. Many veterinarians criticized the education in university, stating it was insufficient to prepare them to perform accurate ultrasound examinations. The challenges surrounding insufficient ultrasound education and insufficient are discussed further in section 5.5.

5.4 Preparation instructions

Survey question eight, dealt with preparation instructions. Preparation instructions should be given when needed to obtain the best possible image quality. Of the 56 veterinarians who are used ultrasound, two did not answer question eight, so the total number of answers in this question was 54. Of these, five (9.3 %) said that they did not give any preparation instructions:

> *"Preparation instructions are not given, because normally it is not known beforehand that ultrasound examination is done."*

Table 5 presents the preparation instructions mentioned in the open-ended question.

Table 5. *Preparation instructions given to animal owners before ultrasound examinations*

Preparation instruction	***n***
When urinary bladder is being imaged, the bladder should be as full as possible.	27
When urinary bladder is being imaged, animal should be 4 - 6 hours without urination	9
12 hours fasting before ultrasound examination of abdomen	6
6 - 10 hours fasting before ultrasound examination of abdomen	4
In situtations where sedation is needeed, spesific fasting instructions are given	4
Fasting 6 - 12 hours, depending of the size of the animal	10
Warning, that sedation may be necessary to complete ultrasound examintion	3
Urinary bladder and intestines should be empty before abdomen ultrasound	2
Urinary bladder and intestines should be empty before gestation checks	2
I work alone, without an assistant	1
Gestation identification be done at the earliest: 21 days for cat and 18 days for dog	1
Preparations instructions are not given at all	5

Table 6 displays, the most commonly mentioned preparation instruction was ‘when urinary bladder is being imaged, the bladder should be as full as possible’. In practice this means the animal should not urinate before ultrasound examination:

> *“In the examination of urinary bladder, there should be urine in the bladder, so carry the animal inside”.*

Most of the answerers did not provide any recommended duration for how long animals should not urinate. Eight respondents recommended four hours and one respondent recommended six hours without urination before ultrasound examination.

According to the results, veterinarians also gave different fasting instructions. Four respondents recommended fasting from six to ten hours, and six recommend twelve hours of fasting, before ultrasound examination of the abdomen:

> *“Before abdomen ultrasound, animal should be fasted for twelve hours and defecated so that intestines are as empty as possible.”*

Along with abdomen examinations, fasting was also suggested because it decreases intestinal gas and because it is safety precaution if sedation or anaesthesia is needed. Depending on the size of the animal, ten veterinarians suggested fasting from 6 to 12 hours before every ultrasound examination.

> *“Cats should be fasted 6 hours before ultrasound examination and dogs 8 – 12 hours (anaesthesia and gas reducing)”.*

Three veterinarians said that they warned animal owners that sedation may be necessary, and four veterinarians stated that they give specific fasting instructions in situations where sedation was needed. Respondent clarified that whether sedation was necessary was always considered on a case-by-case basis:

> *“Specific fasting instructions are given, when fine-needle samples are taken, because the animal has to be anaesthetised”.*

> *“In some situations, sedation is necessary. This is considered always case specific. Purpose is to reduce sway artefacts”.*

One individual’s answer was that animal owners should notice that the veterinarian is working, without assistance. There were also two preparation instructions affiliated with gestation identification:

> *“When the animal is coming in to gestation identification, bladder and intestines should be empty”*

> *“Gestation identification ultrasounds can be done at earliest after 21 days for cats and after 18 days for dogs”.*

5.5 Quality assurance

The purpose of the last multiple choice question was to discover whether quality assurance was performed and how often. Figure 19 below shows the distribution of quality assurance.

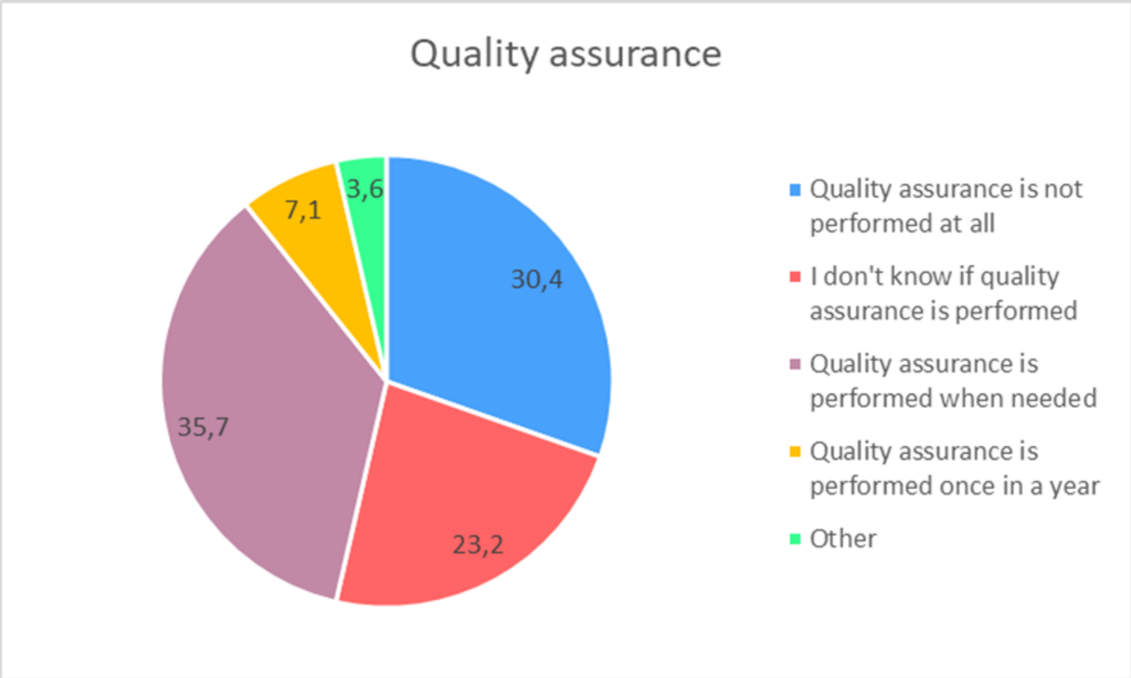

Figure 19. *Distribution of quality assurance.*

As the figure 19 indicates, the 20 of the 56 respondents (35.7%) stated that quality assurance was performed when needed. However, 17 (30.4%) of the veterinarians answered that quality assurance was not performed. In addition, almost one quarter (23.2 %) of veterinarians did not know whether, quality assurance was performed. Only four respondents (7.4 %) stated that quality assurance was performed regularly once in a year.

There were two other answers. One stated that quality assurance is performed continuously.

> *"During the ultrasound examination the image is been watched and observed all the time, so basically quality assurance is done continuously all the time."*

The other single answer indicates that veterinarians do not necessarily know what quality assurance means or what entails:

> *"There are no quality assurance methods available in Finland".*

Figure 20, below, depicts the impact of graduation year to quality assurance.

Figure 20. *Impact of graduation year to quality assurance.*

As figure 20 illustrates, there is slight difference in the quality assurance routines when comparing graduation years. Results show that veterinarians graduating 2009 or after are more inexperienced of quality assurance than those graduating before 2009. For example, 40 % did not know whether quality assurance was performed, only 28% said that quality assurance was carried out when needed and one veterinarian (4 %) answered that quality assurance was performed once in a year.

According to the results, veterinarians graduating before year 2009 were more experienced. The majority of respondents (42%) said that quality assurance was carried out when needed. In addition, three answered that quality assurance was performed once in a year and one said it was done continuously. Only three veterinarians said, they did not know whether quality assurance was carried out.

Analysis of quality assurance answers indicate that specialized veterinarians are more aware of quality assurance. All four specialized veterinarians answered that quality assurance was performed when needed. In addition, the primary learning method had an impact on quality assurance. Three of the four veterinarians who stated that quality assurance was carried out regularly once a year had taken an additional ultrasound course, and the primary learning method of one veterinarian was education organized by manufacturer or retailer. In addition, education included in the studies were the primary learning method of over half of the veterinarians who said they did not know whether quality assurance was performed.

5.6 Major challenges

The last survey question asked what veterinarians consider the major challenges of ultrasound examinations. This question was open-ended, so veterinarians could to freely explain what they thought the major challenges in ultrasound examinations were and why these were challenges.

To handle the varying answers, answers were divided into different categories. The four main categories, were further divided into sixteen subcategories. The first main category, 'behaviour of the animal during the examination' includes three subcategories: 'panting', 'movement of the animal' and 'defending animals'. The second main category is 'shape and structure of the animals'. This category also has three subcategories: 'shape of animals', 'big breeds' and 'variation of body structures'. The third main category is 'poor device', which has four subcategories: 'lack of maintenance', 'transducer', 'poor quality' and' price of new and good devices'. The last main category, 'use of the ultrasound' is the largest with six subcategories: 'insufficient and diminutive ultrasound education', 'inexperience', 'interpretation of the image', 'adjusting imaging parameters',' time consumption' and 'artefacts or intestinal gas'.

The division and distribution of the major challenges are depicted in figure 21 on the next page. In the figure every main and subcategory box includes an abbreviation n. In this situation n, indicates the number of times, each challenge is mentioned in the answers.

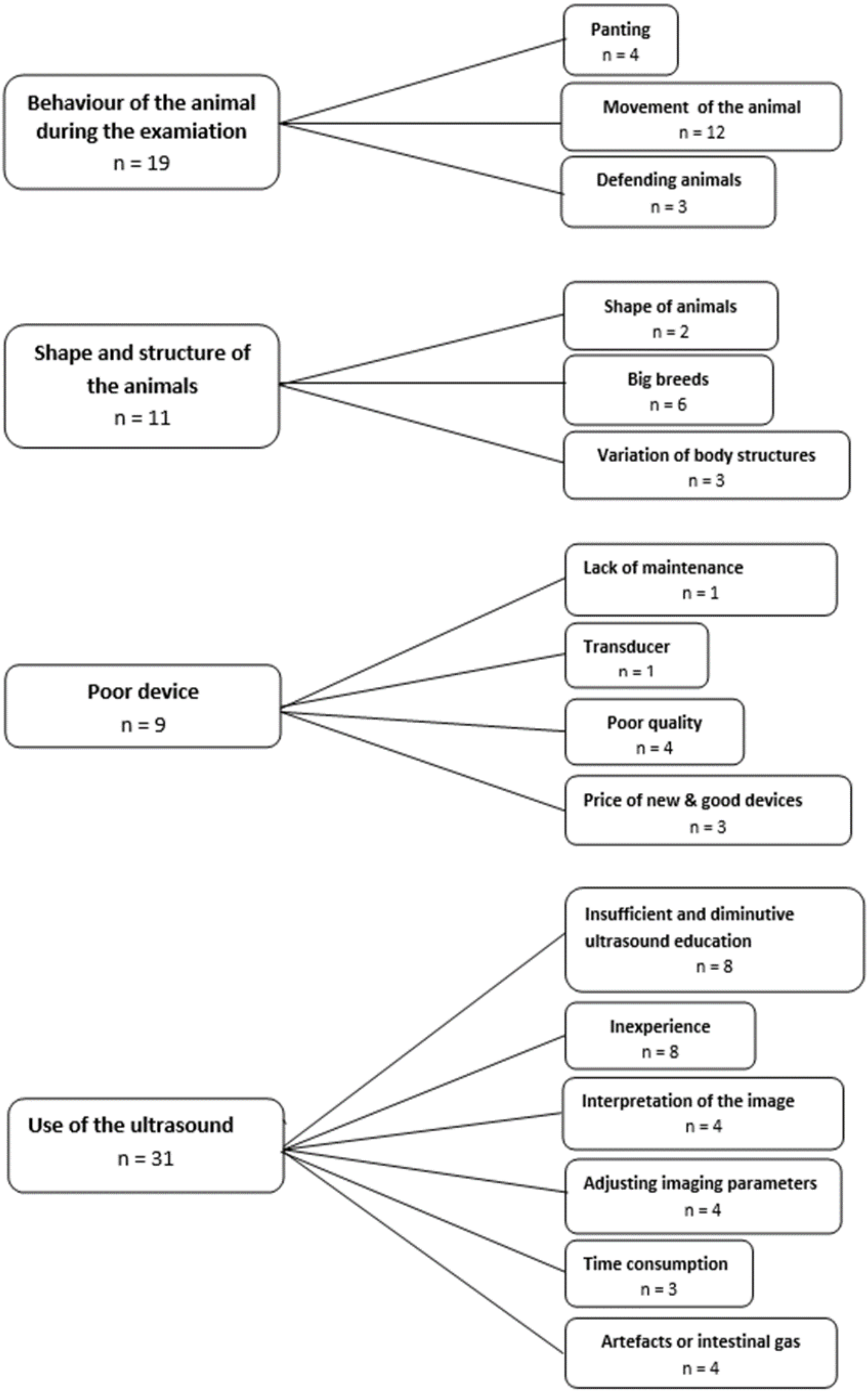

Figure 21. *Major challenges.*

The animal's behaviour during examination was mentioned 19 times as the greatest challenge. From all the challenges mentioned, animal behaviour and animal shape and structure were challenges mainly not dependent on the veterinarian. The most commonly mentioned (n = 12) subcategory was the animals movement during the examination.

> *'Biggest challenge is to get the animal in supine position in an upholstered and robust underlay and to keep the animal still during the whole examination'.*

> *'Moving and wriggling of a awake animal that can not be sedated'*

Certainly, veterinarians can impact an animal's calmness with his or her attitude, and to reduce movement, it is sometimes necessary to sedate the animal to obtain high-quality image. In addition to movement, panting (n = 4) and defending animals were mentioned (n = 3).

The main category, 'shape and structures of the animals', was mentioned 11 times. The most commonly mentioned subcategory (n = 6) was difficulties caused by big breeds.

> *'Visibility of deeper parts of abdomen is weak in big animals'*

> *'Visibility suffers with large (over 30 kilograms) patients'.*

The animal's shape was mentioned two times and body structures variation was three times as the greatest challenge. In the answers, veterinarians explained body shape and structure were difficult because every animal is different.

> *'The difference in size and shape of animals is challenging'*

> *'The body structure of the animals – big breeds versus small breeds and often obesity disturbs the image.'*

The third main category, 'poor device' was mentioned in nine answers. From the subcategories, the price of high-quality ultrasound devices was mentioned three times and a poor quality device was mentioned four times. The subcategories 'insufficient transducer' and 'lack of maintenance' were both mentioned once and justified following ways:

> *'With big dogs, in abdomen examinations sufficient image quality is not achieved with normal transducers in use'.*

> *'The quality of the device is poor, because the device is never maintained'.*

From all the main categories, ultrasound device use was mentioned most often (n = 31). The first subcategory 'insufficient and diminutive education' was mentioned eight times, and all the answers were quite similar;

> *'Education in university is diminutive and there is not enough decent teachers or experts'.*

'Specific education is needed to be able to do proper diagnostic examinations, the university education is not alone enough.'

'The use of ultrasound is not instructed or educated actually at all in basic education in the university'

The subcategory 'inexperience' was also mentioned several times (n = 8). However, most of the answers related to insufficient education. Veterinarians stated that the lack of proper education was often the reason for inexperience. In addition, arguments revealed veterinarians were insecure about their ultrasound profiency:

'There is a wide range of different examinations that a basic practitioner should dominate – it is extremely hard/almost impossible for newly graduate without any experience.'

'To gain sufficient routine, as to be able to separate normal anatomies from abnormalities'

'What I consider as a biggest challenge, is to get more experience and knowledge from more rarely cases'.

Answers indicated veterinarians considered the interpretation of the ultrasound image (n = 4) and intestinal gas and artefacts (n = 4) challenges. Based on the answers, it was difficult for veterinarians to separate normal anatomy from artefacts and abnormalities. Interpretation of the ultrasound image and intestinal gas and artefacts were often mentioned in the same sentence, as in the flowing answers.

'What finding is significant.'

'Artefacts and difficulties of interpretation of the ultrasound image - what finding is normal anatomy and what is an artefact.'

'Intestinal gas (fasting has not been kept or has not helped) causing artefacts and this way disturbing interpretation.'

The subcategory 'adjusting the imaging parameters' was mentioned in four answers. These answers revealed that veterinarians did not know the meaning of the different ultrasound parameters (TGC, dynamic range, depth):

'I don't know how to adjust the parameters, so I am not using majority of the ultrasound features'

'I don't know how to use the ultrasound device properly. In addition, I don't understand the settings – so I don't derive profit from it as much I could.'

'Most difficult is to learn to use the settings of the ultrasound device and adjust the parameters so, that best possible image quality is received and with as few artefacts as it is possible.'

The last challenge veterinarians mentioned, was time consumption (n = 3). Veterinarians complained that often there was not enough time to perform a proper examinations and animal owners do not understand how much time an ultrasound examination could take.

‘Hurry and lack of time to complete proper ultrasound examination’.

‘Often colleagues do not understand what means broad abdomen examination, you can just not quickly, in 10 minutes look at the abdomen and say it has been examined.’

‘There should be properly time scheduled for the ultrasound, often owners think that ultrasound examination takes just few minutes - and often we veterinarians also crumble for this.’

6. DISCUSSION

Based on the questionnaire, ultrasound imaging is a beneficial and widely used method in veterinary medicine. However, questionnaire's answers revealed several deficiencies and challenges that could be improved. In the answers to the last survey question, in particular, veterinarians named many aspects of ultrasound they considered challenges. Almost all of these challenges could be easily improved through development. The most important developmental objects are associated with insufficient education, quality assurance, societal pressure and lack of preparation instructions. In this chapter, I will focus on these themes.

6.1 Insufficient education

Insufficient education was mentioned in the survey several times as the greatest challenge using ultrasound. Analysis of the answers indicated insufficient education was an integrative reason for almost all of the challenges mentioned in the last survey question. According to the survey, only one quarter of the veterinarians mentioned veterinary studies as their primary learning method. In addition, based on the answers, the average number of theoretical (13.5) and practical (5.3) learning hours before starting independent ultrasound examinations were quite small.

One reason for insufficient education is that veterinary medicine is a wide and challenging field. During the six years of veterinary studies, veterinarians have to internalise and learn comprehensively animal nursing. Veterinarians have to be familiar with the anatomical structure and specific diseases of different animals and breeds. Conversely, in human medical field, doctors only need to be familiar with human anatomy and diseases. There are also specialists, such as radiologists, midwives and dentists, but in veterinary clinics, often the same person is responsible of all aspects of patient care. Considering this, it is not surprising that the ultrasound education included in basic veterinary studies is quite limited.

A report written by the Ministry of Education, stated that the operational environment of veterinary medicine is in strong reformation. Based on this, the basic university examination alone enough is not sufficient to respond to the continuously increasing demands and requirements of the veterinary world. The Ministry of Education's target is for more generalized veterinarians to be further educated as specialized veterinarians. According to the report, basic veterinary examination provides readiness to dominate basic tasks, but continuous learning is now a compulsion for veterinarians to manage comprehensively. [43]

The former director of the horse hospital in Viikki discussed some issues in her article. She wrote that the future plan is for 60% of veterinarians to complete specialization. The number of horses, horse hobbyist and horse breeding has increased over the years. Therefore, there is growing need for veterinarians specialized in horse diseases. [44]

One obstacle for further education as a specialized veterinarian is the duration of education. First, becoming licentiate of veterinary medicine (legalized veterinarian) requires six years of studying. Afterward, the veterinarian has to work for at least one year before applying to the degree program for specialized veterinary medicine. The education for a specialized veterinarian lasts three years. [45]

Additional education is also discussed in the national program of animal medicine (2015-2019). The program stated that a municipality as an employee is responsible for veterinarians being competent and able a to participate in additional educations. Evira's recommendation of is eight days of additional education per year [18].

Nevertheless, Evira's recommendation was criticized in this survey's open-ended questions because that employers were not willing to invest in the education, mostly because it takes resources (time and money). Therefore, veterinarians themselves are often responsible for learning and additional education. Evira should constitute some waypoints and requirements according the its continuous learning recommendation. These waypoints and requirements could be the way for veterinarians and employees to participate and invest more on continuous learning.

Veterinarians limited ultrasound education could be provided if education was organized by manufacturer or retailer. Instead of just ordering the ultrasound device and self-studying, veterinarians could engage in additional, offered education.

6.2 Quality assurance

Quality assurance should be performed so possible malfunctions can be noticed with enough time to react to them. In addition, quality assurance is necessary to maintain performance, diagnostic accuracy and safety. Despite the recommendations, regular quality assurance is often neglected. Based on survey results, only 7.1% stated that quality assurance was performed regularly once in a year. Over a third of the respondents said that quality assurance was not performed at all. As it was expressed in the chapter three, the regulation on medical devices used in veterinary medicine is quite complicated, and there is no uniform protocol for quality assurance.

It would be necessary to develop uniform protocols for quality assurance. A model could be taken from X-ray devices, which have strict registration. Every X-ray device should be register to database. Also, there are clear guidelines for quality assurance, and quality assurance is supervised by STUK radiation and nuclear safety authority in Finland. Technical quality assurance should be completed on agreed intervals: after significant repair, after maintenance and occasionally when it is suspected that the operation of the device may have changed. [46]

6.3 Society and operational environment

As mentioned veterinarian's operational environment and job description are in modification. Changes in the society are reflected directly to knowledge demands. The same arguments were mentioned in the Kalevi Paldaniu's dissertation in which he investigated the professional identity of veterinarians. One argument in the dissertation was that small animal medicine is now reminiscent of human medicine.

'Animal owners think that everything is possible and can be done in the clinic'

However, currently, there are nowadays so many different examinations and treatments for small animals that the knowledge, ability and equipment (x-ray, ultrasound, transillumination and endoscopy) of a normal mixed-practitioner veterinarian are not enough to perform all examinations and treatments of small animals. The same dissertation also discussed the expectation of animal owners. [47]

"As a problem, he sees the big expectation of animal owners – considering what they think a mixed-practitioner veterinarian can do with an ultrasound." *[47].*

The hectic modern life-style of a present-day has also had an impact on the veterinarian's work. Time consumption was mentioned as a significant challenge three time. Veterinarians complained of being forced to continuously hurry and their lack of time to complete proper ultrasound examinations. As mentioned in section 5.6, accurate and reasonable ultrasound examination take more than a few minutes. The problem is that normally the veterinarian's schedules is fully booked all day, and the next patient arrives immediately after the previous patient has left. At least for scheduled ultrasound examinations, veterinarians should reserve enough time for the examination and diagnosis.

6.4 Preparation instructions

One development target is also preparation instructions. According to the survey answers, veterinarians recognise the meaning and impact of preparation instructions. Only 9.3% of respondents stated that they did not provide any preparation instructions at all.

However, these answers indicated there are no uniform guidelines for the instructions. For instance, recommendation times for fasting and without urination varied considerably. The suggested time without urination before ultrasound examination of the urinary bladder ranged from two hours to six hours. Fasting times before sedation and ultrasound examination of the abdomen cavity also varied from four hours to twelve hours. The variation was caused by different ultrasound education backgrounds.

Example can be taken from human medicine, where patients get the same preparation instructions. For instance, the hospital district in Helsinki and Uusimaa advices patients to fast at least 3 hours before abdomen examination and avoid chewing gum and sparkling drinks to decrease intestinal gas. In addition, it is instructed to drink enough water, because the urinary bladder should be full. [48]

The hospital district in Helsinki and Uusimaa has also patient instruction for ultrasound examinations of urinary tracts and prostate glands. Patients are advised to drink at least 1 litre fluid two hours before ultrasound examinations. In addition, it is told that the patient is allowed to eat normally. [49]

7. CONCLUSION

The idea of this thesis originated from a discussion with a veterinarian. Another inspiration was lack and difficulty with finding specific literature and material on ultrasound examinations of animals. Because of this, the first aim of this thesis was to explore and evaluate ultrasound imaging methods in veterinary clinics based on literature review. The information on the actual research phase of this thesis was collected from an internet-based questionnaire that was sent to veterinary clinics across Finland. The second objective of this study was development of these imaging methods. The development suggestions were mostly created based on, what veterinarians thought were most challenging matters in ultrasound examinations.

The use of ultrasound imaging in veterinary medicine started almost at the same time as its use in the human medical field, in the early 1960s. Ultrasound imaging procedures and principles are the same in animals as in human and normally the same ultrasound device and transducers used for humans can be used for animals. The advantages of ultrasound imaging are as follows: it is fast, portable, it has a high-quality soft tissue contrast. In addition, it has no harmful biological effects to animals and because it is non-invasive, ultrasound examinations can normally be performed without sedation or anaesthesia. Disadvantages of ultrasound include devices being surprisingly expensive and the considerable time requirement needed to master ultrasound and to understand the parameters.

The study results indicated that almost every veterinary clinic in Finland is using ultrasound. It is used for many different applications, from gestation identifications to examination of the eye. Answers of the survey varied mostly based on graduation year, specialization and primary learning method. For instance, the most common primary learning method (n = 11) for veterinarians graduating before 2009 is an additional ultrasound course. Veterinarians graduating 2009 or after mostly learned to use ultrasound through their studies (n = 11) or by self-studying (n = 7).

Answers of the questionnaire revealed also many deficiencies. Firstly, the ultrasound education is diminutive and insufficient. Because of this, many veterinarians find themselves insecure and don not know how to adjust the ultrasound parameters for a better image quality. Second, the quality assurance was deficient. Only 7.1% of respondents stated that quality assurance was performed regularly once in a year. The reason for this is, the lack of uniform protocol for quality assurance, why it would be necessary to develop uniform protocols and guidelines for quality assurance. Besides these, preparation instructions also require development.

The number of animals has predicted to increase in the future, which also directly affects the number of ultrasound examinations. Unfortunately, this means that the requirements and expectations of veterinarians will continue to grow. Therefore, it would be important that deficiencies are considered and developed. It would be necessary to invest in the ultrasound education and create requirements for quality assurance and preparation instructions.

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APPENDIX A: COVER LETTER

Hi,

I am a student, from Tampere university of technology. I am writing my master's thesis from a subject: "Evaluation and development of ultrasound imaging methods in veterinary clinic". Related to my thesis, I have composed a questionnaire form, where I hope to get as much answers as possible. Answering takes about five minutes and the identity of the answer will not be revealed at any point. If you do not use ultrasound, please answer only to the first question, and send the questionnaire after this. The deadline for answers is 21.12.2017.

Thank you for your answers and have a pleasant waiting for Christmas.

With regards;

Emmi Vehanen

APPENDIX B: QUESTIONNAIRE FORM

Do you use an ultrasound device?

- ◻ Yes
- ◻ No

Profession and graduation year?

____

In which of following alternatives has ultrasound device been used for?

- ◻ Gestation checks
- ◻ Heart examination
- ◻ Examination of blood flow
- ◻ Examination of tumor
- ◻ Urinary bladder disorders
- ◻ Uterine inflammation
- ◻ Abdominal examination
- ◻ Muscle examination
- ◻ Tendon examination
- ◻ Examination of eye
- ◻ Ultrasound guided biopsy
- ◻ Other ____

Approximately, how often us ultrasound used?

- ◻ Under 5 (At least for one of five patients)
- ◻ 6 - 10 (At least for one of ten patients)
- ◻ 11 - 15 (At least for one of fifteen patients)
- ◻ 16 - 20 (At least for one of twenty patients)
- ◻ Over 20 (Less often than for one of twenty)

What do you consider as your primary learning method?

- ◻ An ultrasound course included in studies
- ◻ Practical training place
- ◻ Self studied
- ◻ Education organized by manufacturer/retailer
- ◻ Additional ultrasound course
- ◻ Other: ______________________________________

Approximately, how many theoretical learning hours have you received before starting independent ultrasound examinations?

____

Approximately, how many practical learning hours have you received before stating independent ultrasound examinations?

____

What kind of preparations instructions do you give to animal owners, before ultrasound examinations. For instance, when urinary bladder is being imaged, the bladder should be as full as possible.

____

Do you perform quality assurance and how often?

□ Quality assurance is not performed at all

□ I do not know if quality assurance is performed

□ Quality assurance is performed once in a month

□ Quality assurance is performed once in a year

□ Other: ________________________________

What do you consider as the major challenges?

____